Waste heat recovery potential from beehive coke oven gases

Final report

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Table of contents

List of tables

List of annexures

List of figures

Executive summary

The potential for utilising the waste heat in the coke oven gases of the Usha Udyog plant at Redi are evaluated and presented in this report. The capital cost and the unit cost of generation have been derived. Currently, 5000 tonnes of coal is charged per month and approximately 3500 tonnes of coke is produced in the bee-hive coke ovens.

Potential

3 MW of power may be generated. This figure has been arrived at by carrying out measurements and analysis of the coke oven gases for batteries B1, B2, B3 and B4. Around 13 MW of heat energy at a temperature of 750-800 deg. C is available. This includes the heat from 2 new batteries which are expected to be commissioned soon. Approximately, 23 percent (3/13) of the waste heat can thus be recovered. Conservative values for the equipment efficiencies have been assumed given the size, design and operating parameters of equipment. It is also assumed that there shall be a 20 percent increase in the coke oven production with the existing batteries (B1-B6).

Methodology

The total magnitude of the heat energy available in the waste gases is the product of the mass flow rate of the gas, the specific heat and the temperature. The mass flow rate was derived from waste gas composition which was measured, and the coke production rate. The gas has no combustibles and consists of Carbon dioxide (5-8 percent), Oxygen (4-14 percent) and Nitrogen (over 80 percent).

Equipment

Major equipments required are,

- Three waste heat recovery boilers each of capacity 5 t/hr, generating steam at 44 bar and 445 deg. C.
- One 3 MW condensing turbine and generator.
- A waste gas delivery system.
- Auxiliary plant and equipment for the power houses like, civil works, electrical, control and instrumentation, DM plant, etc.

Financial

The equipment cost obtained from the suppliers varies widely from Rs.8 crores to Rs.14 crores. Accordingly, the pay back period varies from 21 months to 77 months and the internal rate of return from 17 percent to 62 percent. The unit cost of generation varies from Rs.1.00 to Rs.1.93. The decision to initiate this project is thus strongly dependent on the final negotiated price of the equipment.

Caution

The gas delivery system is of critical importance which must incorporate adequate design and operation features such that the coke oven performance does not deteriorate while at the same time ensuring high boiler efficiency.

It is suggested that systematic efforts be made to improve the coke oven performance, by incorporating improved designs and control features.

CHAPTER 1

Introduction

The potential of raising steam and generating power from the waste heat produced by the coking ovens of the Usha Udyog Limited Plant at Redi are evaluated and presented in this report. The methodology used in estimating the magnitude of heat available in the exhaust gases for power generation is described. A financial appraisal has been made for setting up a power station of 3 megawatts capacity.

Process

Coke is produced by heating coal to a high temperature resulting in the removal of volatile matter. The coal charge in each oven is about 12 tonnes. It remains in the oven for 40-60 hours to convert to coke. Approximately 8.4 tonnes of coke is produced per charge. The coal itself is burnt to supply the heat, in a restricted amount of air.

Bee-hive coke oven batteries have been installed at the pig iron plant at Redi in Maharashtra. This plant is located about 60 km North of Panjim (Goa) on the Goa-Maharashtra border. Four coke oven batteries are in operation. Each battery has nine coke ovens. Two more batteries of 9 ovens each are under construction. Approximately 5000 t of coal is processed each month to produce 3500 tonnes of coke. A large volume of high temperature waste gases are produced in the process.

Scope of work

The objective of this study is to determine the magnitude of waste heat available in the coke oven gas that can be used to generate steam and power. The recovery of the waste heat to produce electric power will reduce the overall coke cost assuming that the power generated can be either sold or consumed in the pig iron plant to offset purchased power. However, coupling the waste heat recovery to the non-recovery oven process has not yet been accomplished in the country. Therefore, M/s Usha India Limited sponsored a study to the Tata Energy Research Institute for assessing the potential of power generation from the waste heat in the coke oven gases and the economics of power generation. The scope of work is as follows:

- Assessing the average quantity of coke oven gas discharged and its temperature, constituents and calorific value.
- Suggest the optimum technology to be adopted for power generation and also possible alternatives with details of associated benefits.

- Assessment of the optimum and maximum capacity for power generation for arriving at suitable investment.
- Determine the cost of power generation based on capital cost estimates and optimum utilization.

Methodology

The waste heat available for steam generation is a product of the mass flow rate of gas, the temperature and the specific heat. The mass flow rate of gas was obtained indirectly by determining the flue gas composition. The air/fuel ratio derived from the flue gas composition was multiplied by the coal burning rate (from plant records) to give us the mass flow rate of flue gas (refer chapter 2). Temperatures of the exhaust gases were measured.

Using appropriate boiler and turbine efficiencies the power generation potential, capital cost of equipment have been computed and the cost per unit of generation have been derived.

Details of measured data and analysis are described in Chapter 2. Assuming a 20% improvement in performance, the power generation potential is 3 MW.

Findings

Accordingly, a 3 MW Turbo generator set is suggested. Three boilers of a rated capacity of 5 t/hr to generate steam of 44 bar, 445°C shall be required. A gas delivery system with such design and operating features that the coke oven performance is unimpaired is required.

A financial analysis have been carried out for 90% and 100% capacity utilization. In each scenario three cases have been considered.

Case I	:	Low cost vendor (capital cost Rs.8 crores)
Case II	:	Medium cost vendor (capital cost Rs.12 crores)
Case III	:	High cost vendor (capital cost Rs.14 crores)

The project viability is strongly dependent on the final negotiated price of the major equipments. Between the high and low investment values the internal rate of return varies from 17% to 62% respectively. It may be concluded that the project is attractive for the low and medium cost estimates (i.e., case-1 and case-2 respectively).

The summary of the project results is included in Table 1.1.

- The waste heat available is approximately 13250 KW after all the 6 batteries are in operation. This can generate 11.5 t/hr of steam at 44 bar and 445 deg.C to give 2.5 MW of power. If the performance of the ovens is improved by 10 percent (which is expected) through proper control of operations, the steam generation would be

12.6 t/hr, giving a power output of 2.7 MW. Similarly, if the performance of the plant is improved by 20 percent, the steam and power generation would be 13.8 t/hr and 3.0 MW respectively. Therefore, 3 nos. of 5 t/hr steam generating capacity boilers and one 3 MW turbo-generator system (condensing type) have been recommended.

- For the first scenario, i.e., at 90 percent utilization and based on the low cost of waste heat boiler, the project will entail a financial outlay of Rs.8 crores and generate net revenues of Rs.3.89 crores per annum, thus giving a payback period of 25 months. The internal rate of return (IRR) is calculated to be 53 percent. For the medium cost of boiler the capital outlay is 12 crores, payback period 51 months and IRR 25 percent. If the upper cost of the waste heat boilers is taken, the capital investment rises to Rs.14 crores with a net revenue generation of Rs.2.19 crores. This gives a pay back period of 77 months and an IRR of 17 percent.
- In case of the second scenario of 100 percent utilization of turbine capacity, the Case 1 indicates a financial outlay of Rs.8 crores and net revenue of Rs.4.58 crores with a pay back period of 21 months and IRR of 62 percent. In Case 2 capital cost is 12 crores, net revenue is Rs.3.48 crores with a pay back of 41 months and IRR of 32 percent. In case 3 the capital investment is 14 crores, net revenue is 2.87 crores with a payback of 59 months and IRR of 22 percent.

There is a wide variation in the costs of the equipment from Rs.8 crores to Rs.14 crores. Hence the final decision to initiate this project will depend on the negotiated price of major equipments. Conclusion and recommendation are listed in the last chapter.

Caution

It is of critical importance that a gas delivery system be designed with adequate operating features to ensure that the performance of the coking oven does not deteriorate while maintaining a high efficiency of the boiler.

Table 1.1. Power generation from coke oven gases at Redi - Project at a glance

Item	Units	90 % capacity utilisation			100 % capacity utilisation		
		Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Number of batteries		6	6	6	6	6	6
Number of ovens		54	54	54	54	54	54
Mass flow rate of waste gases	kg/sec	25.5	25.5	25.5	25.5	25.5	25.5
Magnitude of heat available	MW	13	13	13	13	13	13
Steam generation	tons/hr	13.8	13.8	13.8	13.8	13.8	13.8
Power generation capacity	MW	3	3	3	3	3	3
Total power generation	MkWh	21.6	21.6	21.6	24	24	24
Auxiliary consumption	MkWh	1.08	1.08	1.08	1.20	1.20	1.20
Net generation	MkWh	20.52	20.52	20.52	22.80	22.80	22.80
Total capital cost	Rs.Crores	8	12	14	8	12	14
O & M cost	Rs.Crores	0.2	0.3	0.35	0.2	0.3	0.35
Total cost of production	Rs.Crores	2.26	3.36	3.97	2.26	3.36	3.97
Total gross revenue	Rs.Crores	6.16	6.16	6.16	6.84	6.84	6.84
Net revenue	Rs.Crores	3.89	2.79	2.19	4.58	3.48	2.87
Unit cost of power	Rs/kWh	1.10	1.64	1.93	1.00	1.47	1.74
Payback period	months	25	51	77	21	41	59
IRR	%	53	25	17	62	32	22

CHAPTER 2

Power generation potential

Technology to be adopted for power generation

In India, there are many waste heat boiler installation in process industries and large petro-chemical plants where these equipments have been integrated with the process design. The scale of waste heat recovery systems would depend on the specific properties of the heat source i.e., temperature, pressure and flow rate and its availability. When the temperature of waste gas is above 350°C, steam production usually is the most economic method of heat recovery. Water tube boiler is usually the logical choice for high pressure steam. The water tube boiler consists of drums and tubes with the drums acting as reservoirs for water and steam.

The pig iron plant at Redi has a definite requirement of power which is partly purchased from Maharashtra State Electricity Board. Therefore, the waste heat in the coke oven gas can be utilized to generate steam in waste heat boilers. Waste heat boilers can be installed downstream of the exhaust gases issuing from the coke oven battery. The ducts carrying the exhaust gases from the outlet of the ovens will be so routed that they will enter the boiler during normal operating conditions or will have the provision of being vented through the emergency exhaust stack in the event the boiler is not on line. The steam generated from the three boilers can then be piped via a header to the steam turbine for power generation.

Assessment of available heat in the coke oven waste gases

To assess the available heat in the coke oven waste gases, the following information has to be monitored and computed:

- Waste gas composition and air to fuel ratio
- Mass flow rate of waste gases
- Waste gas temperature
- Magnitude of heat available

Waste gas composition and air fuel ratio

Twenty-two (22) samples of waste gas were collected from the batteries between March 8-11, 1996. The waste gas composition was determined using the Orsat apparatus. The results are tabulated in Tables 2.1 to 2.4. Oxygen content in batteries B3 and B4 are much higher at 14% and 11% respectively than in batteries B1 and B2. The air/fuel ratio was

determined from the gas composition by balancing the constituents of the chemical equation. CO2 and O2 are the main constituents.

Lower values of air to fuel (A/F) ratios have been selected for the calculation of waste gas quantities. The selection is on the basis that the coking ovens shall work with the minimum amount of air. In batteries B3 and B4, the air/fuel ratio is higher ranging from 3.5-6.85.

Some gas samples were analysed for presence of combustible constituents like CH4, hydrogen in a gas chromotograph. There was no trace of these elements in the samples. (Reference Figure 2.1 - 2.4).

Table 2.1. Waste gas composition-Battery no.B1

	9.3.96				8.3.96	11.3.96
Constituent	1400 hrs	1630 hrs	1130 hrs	1030 hrs	1500 hrs	1000 hrs
CO2	8.8	7.8	8.0	6.4	8.0	7.4
O2	3.8	6.2	5.0	4.2	7.6	6.2
CO	0.0	0.0	1.0	0.0	0.4	0.0
A/F	21.7	24.4	21.7	25.3	24.1	25.1
waste gas (kg/s)	3.5	3.95	3.5	4.09	3.9	4.1

Table 2.2. Waste gas composition-Battery no.B2

	9.3.96			8.3.96	11.3.96
Constituent	1400 hrs	1630 hrs	1130 hrs	1500 hrs	1000 hrs
CO2	8.0	7.0	5.0	7.0	6.4
O2	6.0	4.2	11.6	5.8	10.8
CO	0.4	0.0	0.0	3.2	0.0
A/F	23.2	24.3	37.2	20.8	31.6
waste gas (kg/s)	3.89	4.08	6.25	3.49	5.3

Figure 2.1. Waste gas composition - Battery B1

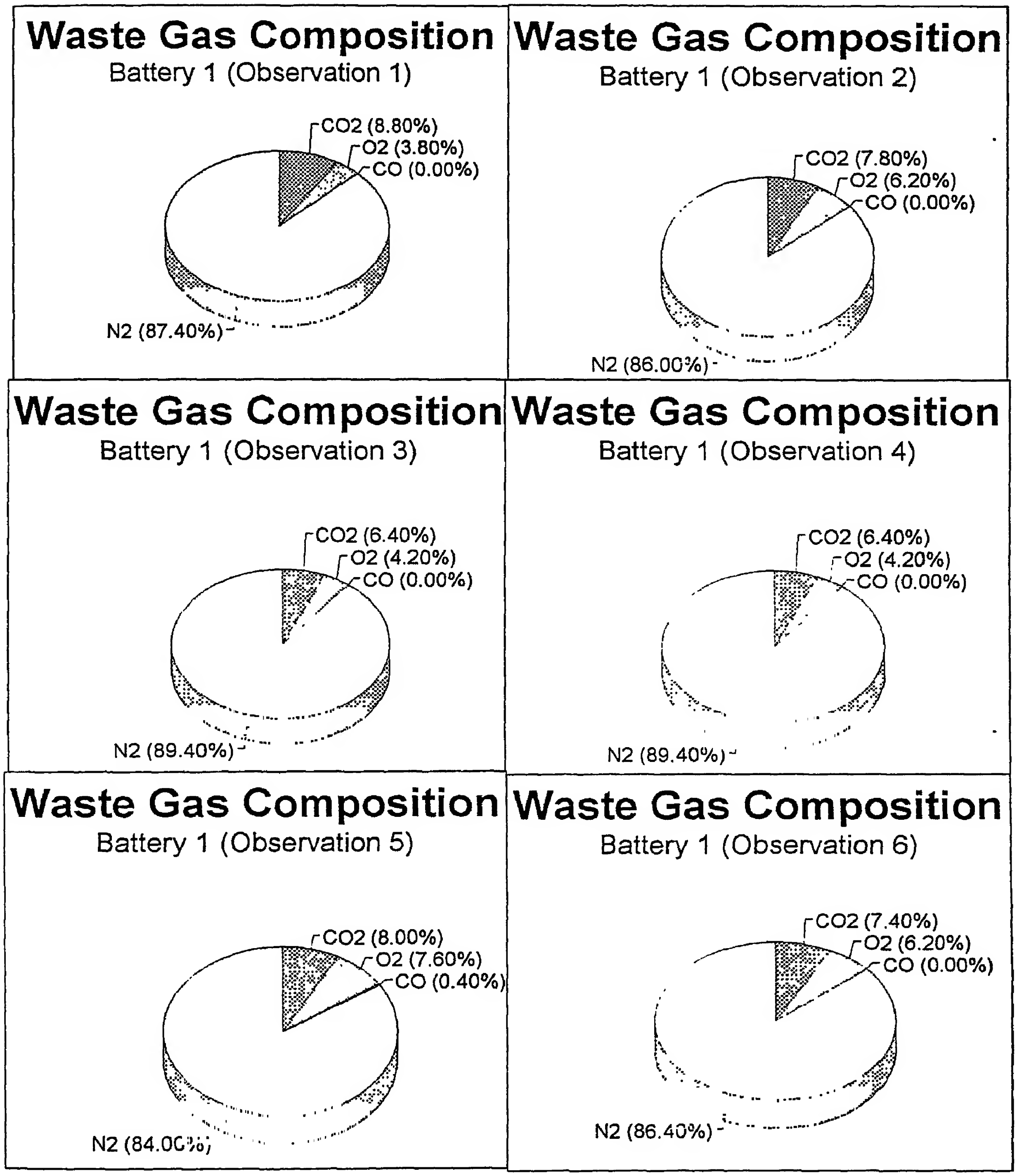


Figure 2.2. Waste gas composition - Battery B2

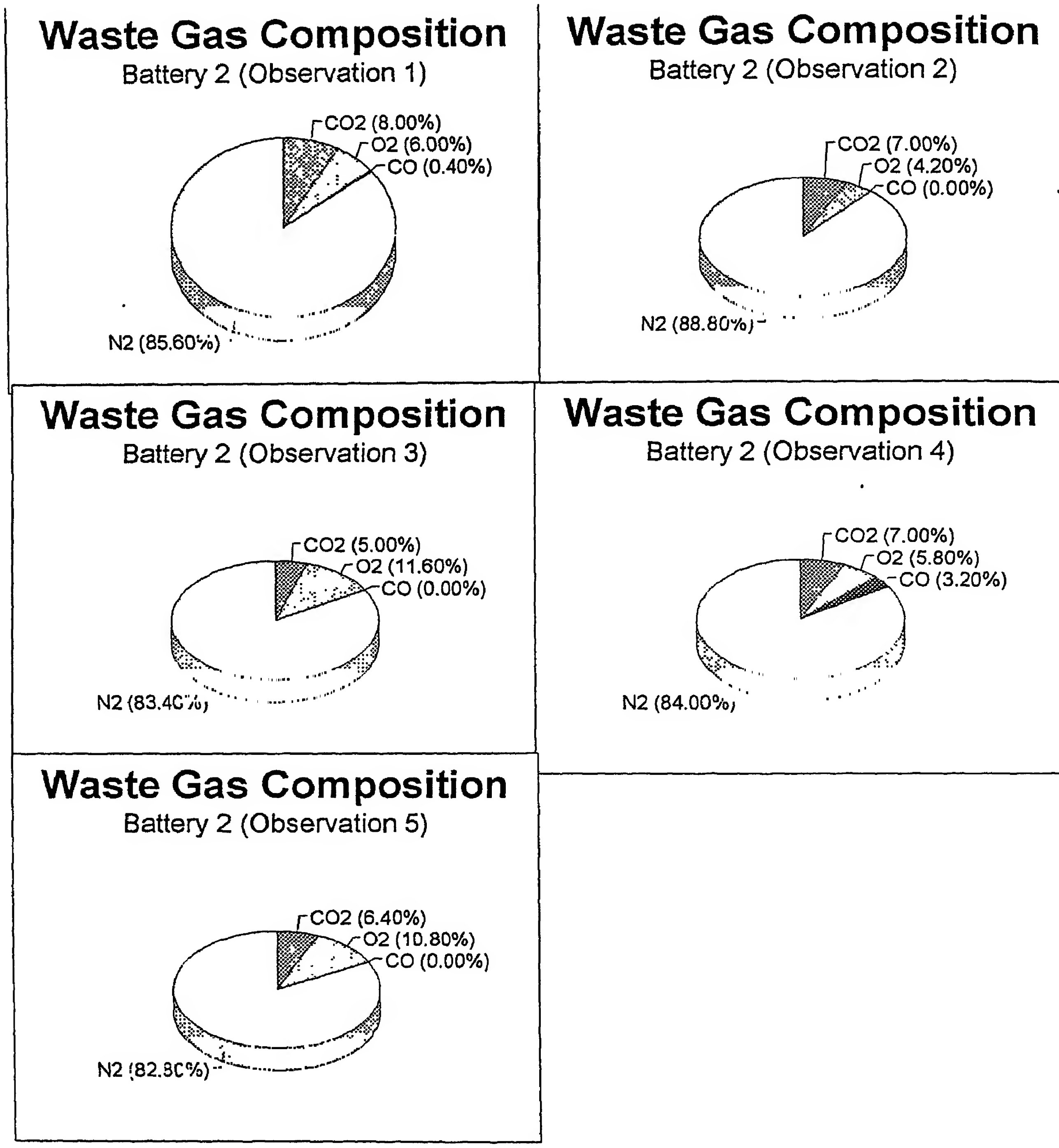


Figure 2.3. Waste gas composition - Battery B3

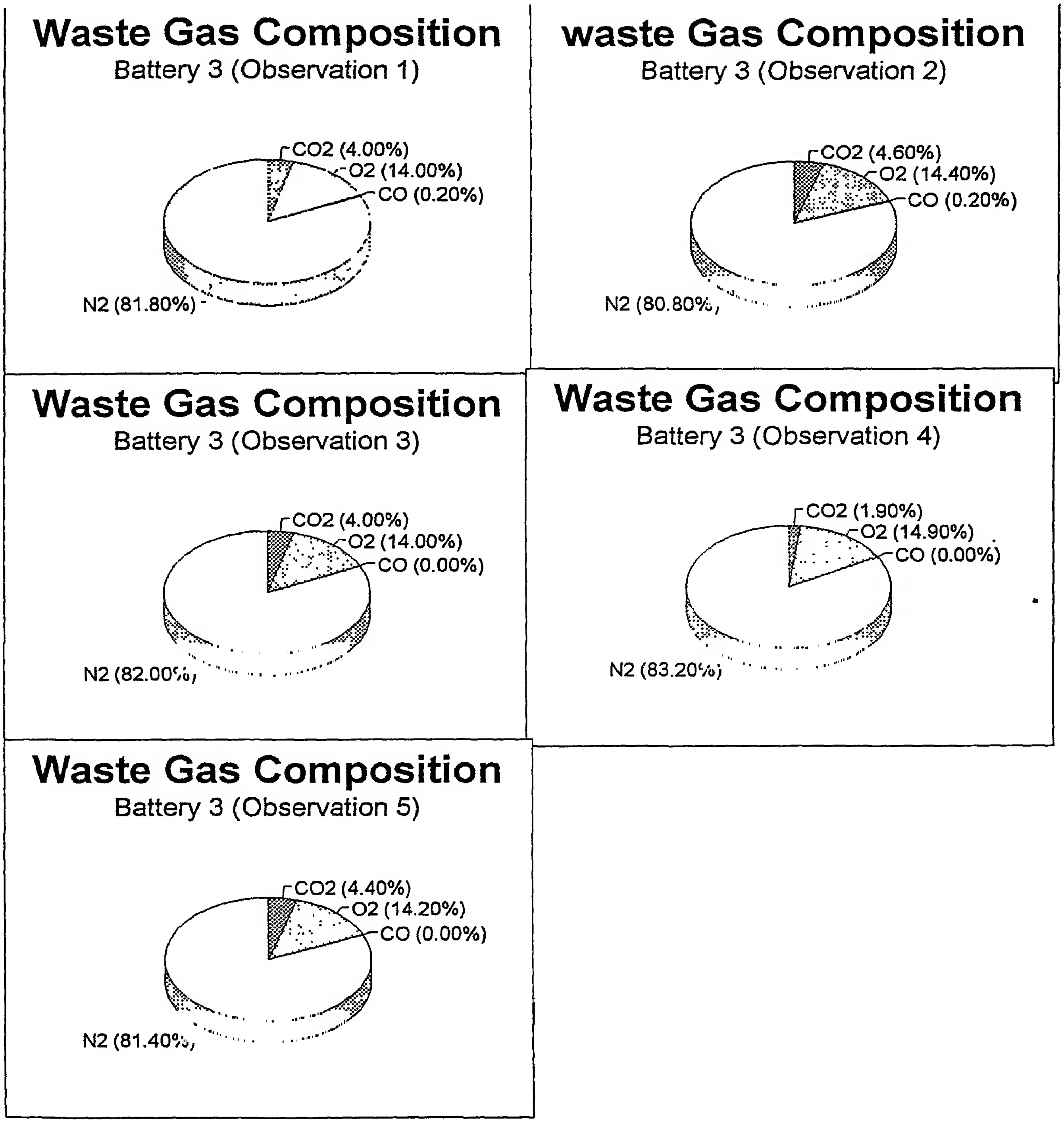


Figure 2.4. Waste gas composition - Battery B4

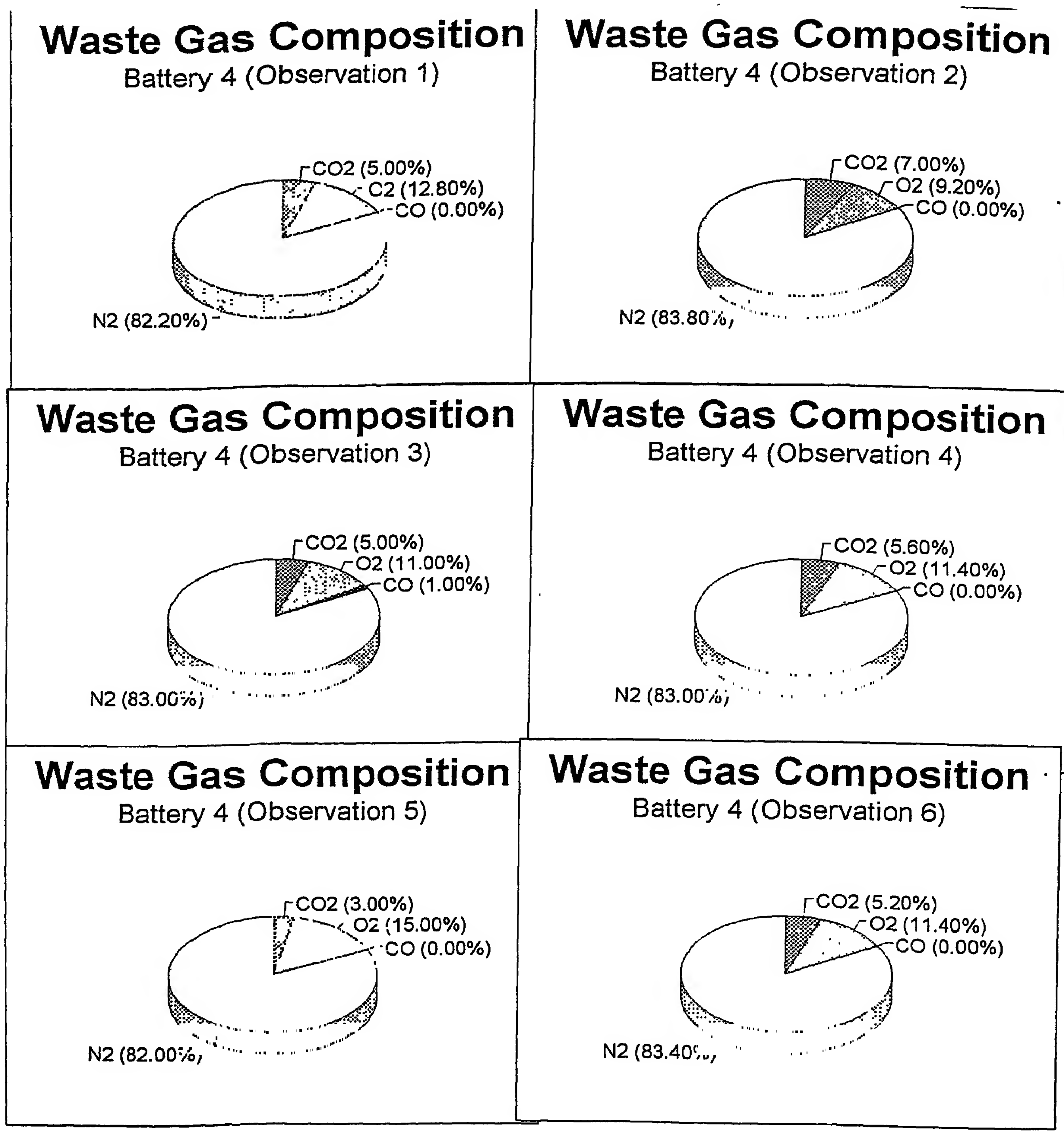


Table 2.3. Waste gas composition-Battery no.B3

	9.3.96			8.3.96	11.3.96	
Constituent	1400 hrs	1630 hrs	1130 hrs	1500 hrs	1000 hrs	
CO2	4.0	4.6	4.0	1.9		4.4
O2	14.0	14.4	14.0	14.9		14.2
CO	0.2	0.2	0.0	0.0		0.0
A/F	24.5	44.1	47.6	69.2		46.0
waste gas (kg/s)	3.53	6.35	6.85	9.96		6.6

Table 2.4. Waste gas composition-Battery no.B4

	9.3.96				8.3.96	11.3.96
Constituent	1400 hrs	1630 hrs	1130 hrs	1030 hrs	1500 hrs	1000 hrs
CO2	5.0	7.0	5.0	5.6	3.0	5.2
O2	12.8	9.2	11.0	11.4	15.0	11.4
CO	0.0	0.6	1.0	0.0	0.0	0.0
A/F	39.5	27.1	32.3	34.8	58.7	36.1
waste gas (kg/s)	5.56	3.82	4.55	4.9	8.27	5.1

Mass flow rate of waste gases

There are two methods to calculate the mass flow rate of waste gases. One is the direct measurement of the gas flow velocity and the second method is based on the flue gas composition and the quantity of coal burnt. In this study, the indirect method has been used since the flow measurements using pitot tube could not give acceptable results.

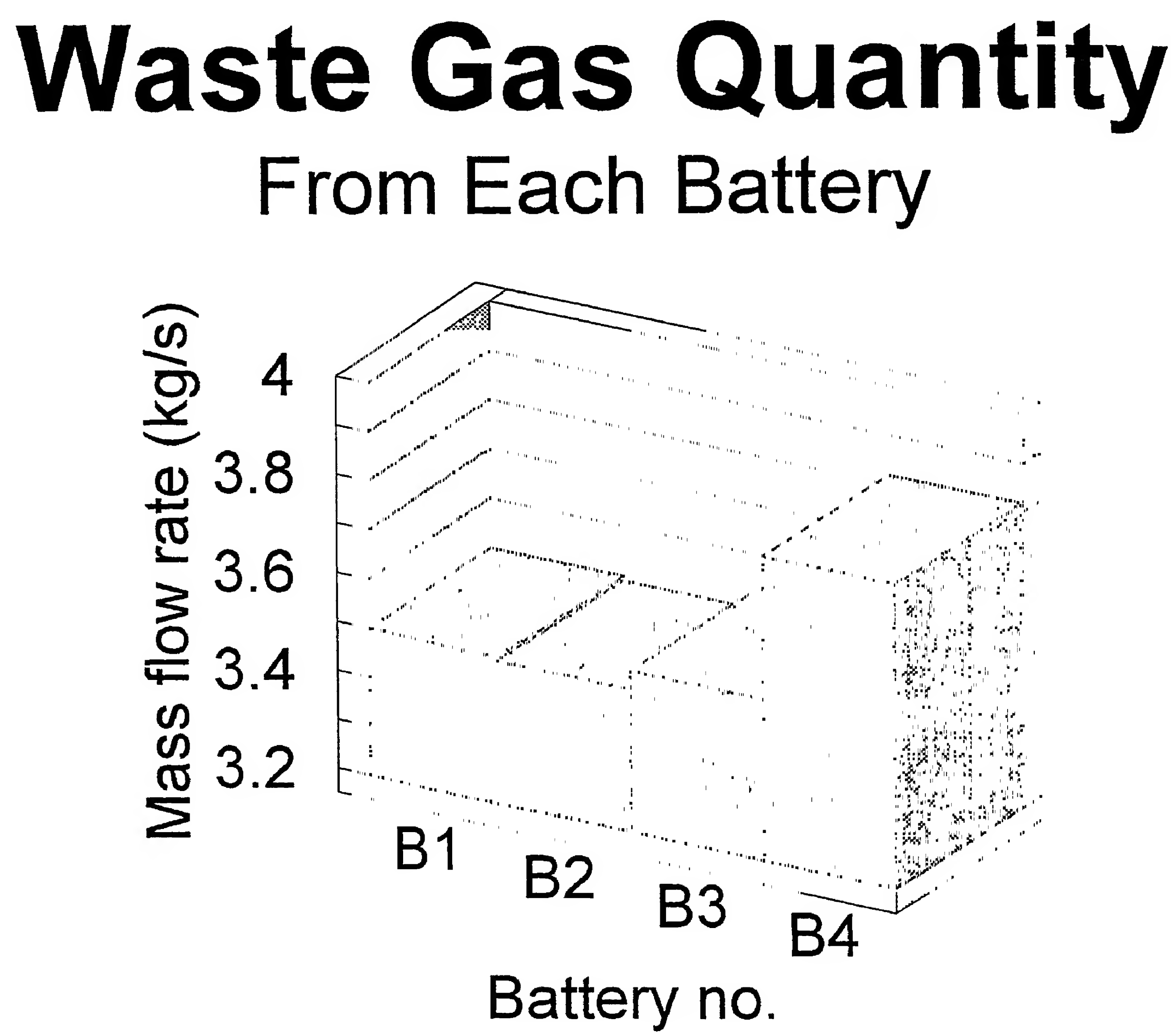
Direct method

Direct measurement of the flow velocities are difficult as the flow velocities are very small. Attempts to use the pitot static tube show a velocity head of less than 1 mm of water column, which is impossible to read with the available manometers.

Indirect method

Samples of gas were collected and analysed to give their composition and thereby determine the air/fuel ratio. From the plant operating records, the coal charged and coke produced was obtained and hence the waste gas flow is determined by multiplying the air fuel ratio with the coal burnt. Figure 2.5 presents the quantity of the waste gases generated from each battery i.e. B1, B2, B3 and B4.

Figure 2.5. Waste gas quantity



Waste gas temperatures and pressure

Waste gas temperatures measured at the main tunnel of each battery and the bottom of stack are tabulated in Table 2.5. and depicted in Figure 2.5. Batteries B1 and B2 are connected to stack S1 while batteries B3 and B4 are connected to stack S2.

B1 and B2 temperatures are much higher than those of B3 and B4, the difference varying from 100 to 245 deg C. The oxygen content in the waste gas is higher in tunnel B3 and B4 which cools the waste gas.

There is a sharp drop in temperature of the waste gas from the tunnel to the stack varying from 130 to 180 deg C for S2 while it varies from 99 deg C to 281 deg C for B1, B2 and S1. Air leaking in from the inlet damper to the stack accounts for such large temperature drops.

The pressure in the main tunnel and the stack is 13 to 17 mm, and 22 mm respectively below atmosphere.

Table 2.5. Waste gas temperatures (as measured) in the main tunnel and bottom of stack of each battery

(figures in degree centigrade)

Measurement details		Batteries				Stack bottom	
Date	Hours	B1	B2	B3	B4	S1	S2
8.3.96	1445	786	846	687	684	676	543
	1545	787	842	685	681	653	541
	1645	862	838	685	679	672	537
	2030	823	925	670	648	702	518
9.3.96	0845	833	808	639	713	687	536
	0945	846	804	638	715	631	538
	1045	878	807	636	716	597	536
	1215	849	837	636	715	586	537
	1430	876	858	631	708	587	535

Magnitude of heat available

Heat available is a product of the mass flow rate of gas, specific heat and the temperature difference. The waste gas temperature at outlet is taken as 225 deg C. The waste gas flow rate of each battery, and the temperature difference are listed in Table 2.6.

Figure 2.6. Waste gas temperature

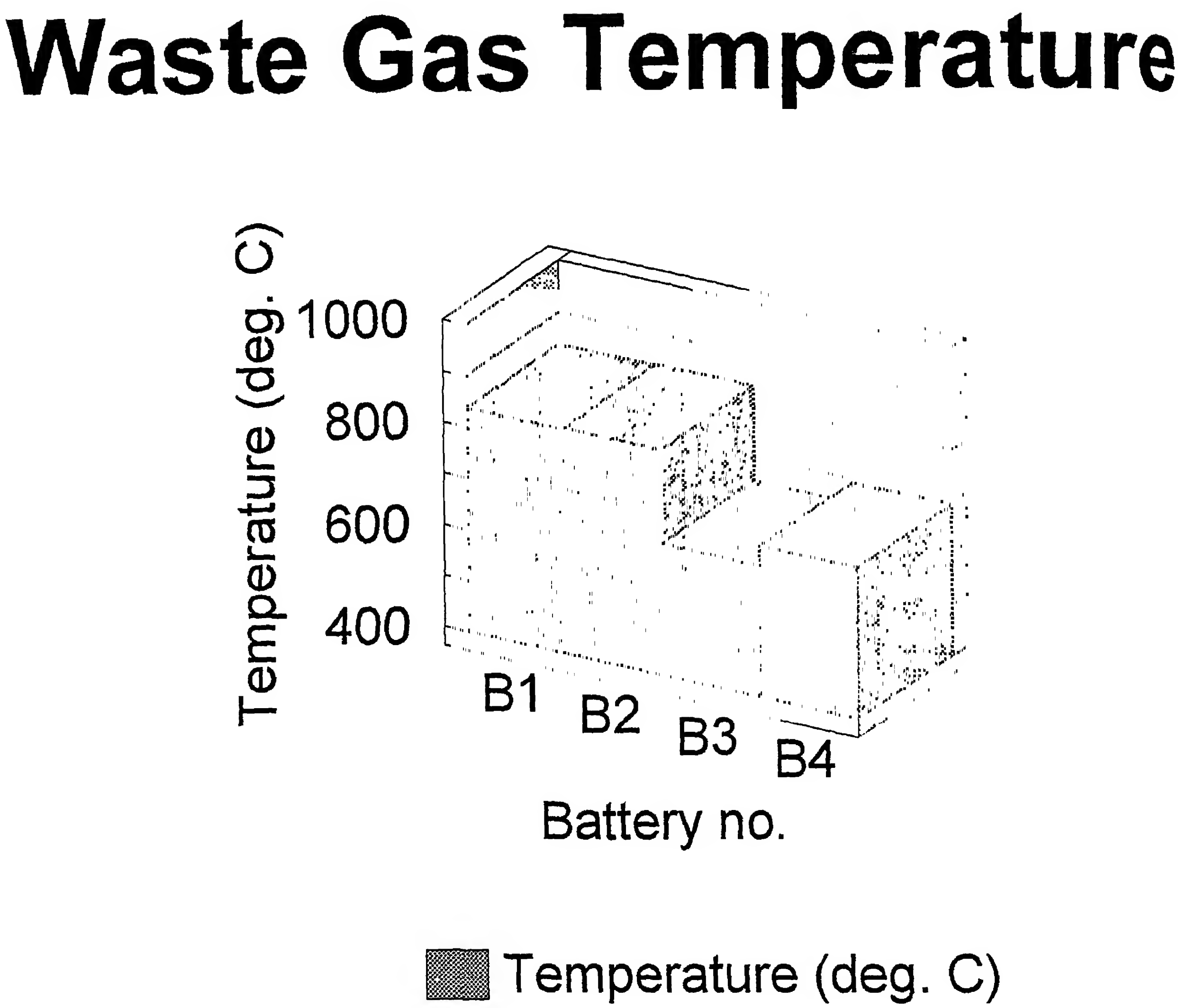


Table 2.6. Heat available from flue gases in each battery

Battery #	Waste gas kg/s 1	Temperature difference ° C 2	Specific heat kJ/kg K 3	Heat in waste gas kW
B1	3.5	555	1.15	2234
B2	3.49	615	1.16	2490
B3	3.53	460	1.132	1838
B4	3.82	455	1.131	1966
Total	14.3			8528

Steam and power output

From four batteries which are in operation.

The steam parameters selected are the same as required by the steam turbine in use at the Redi plant, i.e., 44 bar, 445 deg C. The total heat available is 8528 kW. Taking the ***boiler efficiency as 0.8***, the steam that can be generated is obtained by dividing the available heat with the enthalpy of steam at the parameters given above and works out to be 2.06 kg/s or 7.4 t/hr for all the four batteries. The condenser pressure is assumed to be 0.1 bar absolute. The power output shall vary according to the condenser pressure selected. Lower pressures shall given greater output. Capital and operating costs shall correspondingly be higher. A study is required for optimising this pressure selection. Taking the condensing ***turbine efficiency as 0.7***, the power generated based on 7.4 t/hr of steam at 44 bar and 445 deg. C would be 1.6 MW.

From six batteries in operation and improved oven performance

Battery 5 and 6 would be operational in a few months time and assuming that their performance is similar to existing batteries 1 and 2, the total steam output works out to be 11.5 tonnes per hour and the corresponding power output would be around 2.5 MW.

The improvement in performance of coking ovens shall be the outcome of reduction in coking time. The coking time can be reduced by preventing air leakages from doors and dampers. The dampers have to be properly designed and controlled. The coke oven doors have to be replaced by better insulated doors to reduce high radiation and convection losses.Assuming that coke oven performance increases by 10% and 20% ,the power output would be 2.7 MW and 3 MW respectively. The details are given in Table 2.7.

Table 2.7. Steam and power generation potential with 6 batteries in operation

Coke oven performance	Waste gas kg/s	Steam Output t/hr	Power MW
At current levels of performance	21.3	11.5	2.5
10% improvement	23.4	12.6	2.7
20% improvement	25.5	13.8	3.0

Power plant sizing and generation potential

Waste heat boiler technology

The sizing of the power plant is based on the waste heat available in the waste gases from the coke-ovens. Waste heat boilers are the only solution for recovering heat from the gases. It is technically feasible to have one boiler for each pair of batteries installed adjacent to the coke ovens main tunnel. It is proposed to install one number waste heat boiler common for two batteries. In all there will be three boilers for 6 batteries. The steam generated from the boilers can be piped via., a common piping to a single steam turbine located in the power station building adjacent to the boiler house and coke ovens. The actual location of boilers and turbine houses has to be decided after a proper engineering study by the plant authorities. The technical specification of the boilers are as follows:

Gas Data	
Gas flow rate (Kg/sec.)	7.0
Gas temperature at inlet (deg. Centigrade)	750
Gas temperature at outlet (deg. Centigrade)	180-225
Pressure (mm of water column)	13-17
Steam data	
Superheated steam pressure at battery limit bar(a)	44
Superheated steam temperature at superheater outlet (deg. C)	445+/-5
Steam generated at superheater outlet	5-6 tonnes/hr. from 2 batteries
Feed water data	
Type of boiler	Water tube boiler
Operating temperature (deg. C)	105

Power generation potential

Since the coke ovens will be in operation throughout the year it is proposed to size the power plant for a maximum specific generation of 8,000 kWh per KW (i.e., a PLF of 91.3%). The steam turbine is condensing type and technical specifications briefly are as follows:

Steam Turbine

Type	:	Multistage, Horizontal, Impulse, Axial Flow, Condensing Turbine
Inlet steam pressure	:	45 bar (g)
Inlet steam temperature	:	445.C
Condensing pressure	:	0.14 bar
Rating	:	3.0 MW
Steam flow	:	14.70 T/Hr
Specific steam consumption	:	4.90 kg/KW-Hr

Alternator

Capacity	:	3.0 MW
Voltage	:	415 V
Frequency	:	50 Hz
Rotating speed	:	1500 rpm
No. of poles	:	4
No. of phases	:	3
Insulation	:	Class 'F'
Power factor	:	0.8 (Lagging)
Duty	:	Continuous

Infrastructure requirements and project schedule

For setting up of a power plant based on waste gases from the coke-oven,the following aspects have to be considered.

- Availability of adequate land
- Availability of water
- Adequate facilities for evacuation of generated power.
- Civil Works

Land requirement

Adequate land is available near the coke-oven for setting up the power plant.

Requirement of water

Closed loop recirculating system with cooling tower is envisaged for condenser cooling and auxiliaries. Additional make up water is required to compensate for cooling tower evaporation, drift and blow down losses. Demineralised water is required for boiler make-up. The entire water for the plant will be drawn from the existing lake through pipelines.

Power evacuation

It is assumed that the power generated from the plant, after meeting the station auxiliaries, will be dispatched to the sub-station of the pig iron plant.

Plant and Equipment

Mechanical Equipment

- Steam generator package including draft systems.
- TG package including condenser, condensate pumps, air removal systems, lubricating oil systems, deaerator.
- Power cycle piping, CW piping, steam supply piping, valves etc.
- Cooling tower excluding civil works.
- Circulating water pumps and drives.
- Instrumentation and control panels.
- DM plant and miscellaneous tanks.
- Water treatment plant including clariflocculator
- Compressed air plant.
- Turbine oil purification systems.
- Crane and hoists.
- Ventilation and air conditioning
- Fire protection systems.
- Workshop equipments.
- Power Evacuation.

Electrical equipment and systems

- Power transformer including Generator Transformer, Unit Aux. Transformers, Station Transformers. Lake water pump Transformers, Lighting Transformers.
- 415 V Switchgear including ACDC boards, MCC and Control Panel.
- Power, Control Cables, Instrumentation, Bus Ducts etc.
- DC Supply including Battery & Battery Charger, Distribution Board etc.
- Illumination System.
- Grounding and Lightning Protection.

Civil works

- Power house main building including turbo generator, control panels, compressor room, battery room etc.
- Water reservoirs of RCC construction
- Cooling tower .
- DM plant building, acid/alkali yard, neutralising pit. storage tank and pump house.

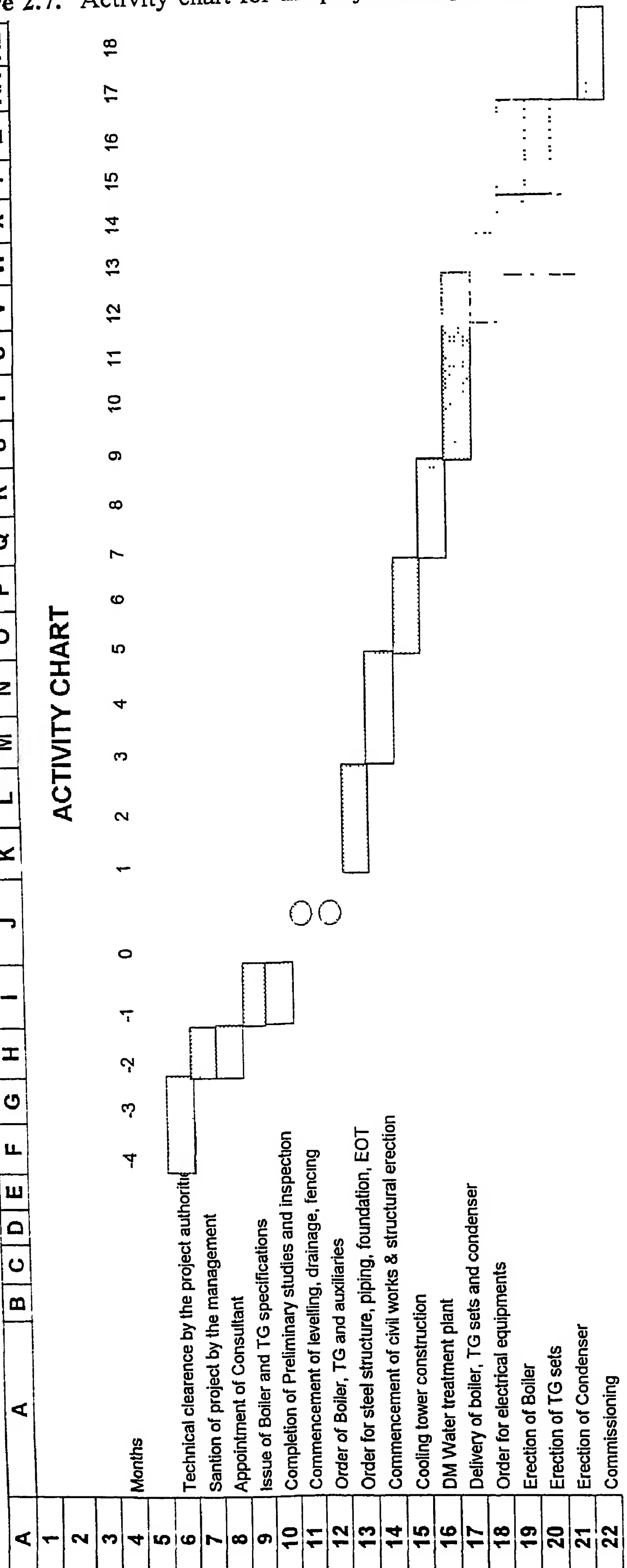
The power plant can be commissioned in 18 months after placement of order for main equipments. A milestone chart is given below indicating the major activities and the time schedule for the activity. The erection and commissioning period is assumed as 6 months after delivery of equipment at site.

Activities

Activity	Month
- Technical clearance by the project authorities	-4
- Sanction of the project by the management	-2
- Appointment of the consultants	-1
- Issue of boiler and TG specifications	-1
- Completion of preliminary studies and site inspection	-1
- Commencement of levelling, drainage, fencing at site	0
- Order of boiler, TG and auxiliaries	0
- Order for steel structure, piping, foundation EOT cranes, piping etc.	2
- Commencement of civil works and structural erection	4
- Cooling towers construction	6
- DM water treatment plant	8
- Delivery of Boiler, TG set, and condenser	12
- Order for Electrical equipments	8
- Erection of boilers	16
- Erection of TG sets	16
- Erection of condenser	16
- Commissioning	18

Figure 2.7 gives the Activity Chart for the project components.

'igure 2.7. Activity chart for the project components



CHAPTER 3

Bee-hive coke ovens

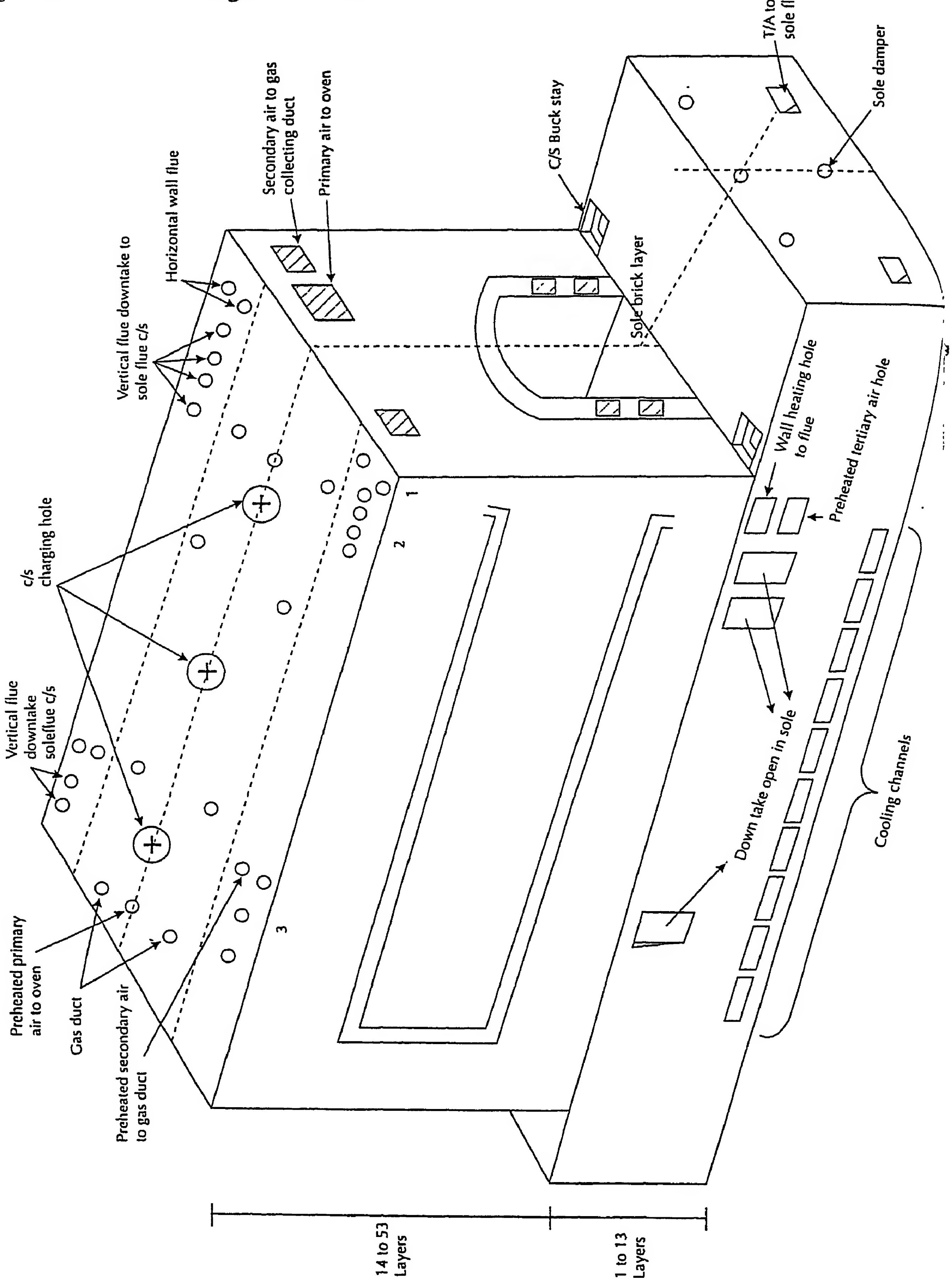
Introduction to bee-hive coke oven process

When coal is heated to high temperatures, in the absence of air, the complex organic molecules break down to yield gases, liquid and solid organic compound of lower molecular weight and a relatively non-volatile carbonaceous residue. This residue from the destructive distillation of coal is called coke. It has many applications including using in a blast furnace for smelting iron ore. Structurally it is a cellular, porous substance which is heterogeneous both in physical and chemical properties. There are two proven processes for manufacturing metallurgical coke, the non recovery type of ovens or the Beehive process and the Byproduct process. Both are batch processes. The characteristic feature of a Bee-hive coke oven is the production of necessary heat by combustion within the oven. It is the oldest form of oven used for carbonizing coal.

In the Beehive process, air is admitted to the coking chamber in controlled amounts for the purpose of burning the volatile products distilled off from coal which generates heat for further distillation. In this process valuable byproduct chemicals are lost and the process causes considerable air pollution. The heat in the unburned portions of these liquid and gaseous products as well as the sensible heat of these gases is also lost. The magnitude of this loss led to the development and application of the waste heat recovery oven. The Central Fuel Research Institute in Dhanbad and Mr Dasgupta and company, Dhanbad have developed an improved version of Beehive oven with improvement in yield and reduced atmospheric pollution. The improved Beehive ovens are sole (floor) heated type. Such non-recovery coke ovens with mechanisation and pollution control measures are operating in other parts of the world.

These ovens are built of firebricks and coal is charged at the top through charging holes and the charge is levelled off through the side door. Gases are driven off by the sensible heat remaining in the floor, oven walls and roof from the previous charge. The coking action is downward. The control of the amount of air admitted through different holes is important, else the coke itself would be consumed. The amount of air is reduced as the coking proceeds to prevent coke loss. A schematic diagram of a coke oven is given in Figure 3.1.

Figure 3.1 Schematic diagram of a coke oven



When the coking is complete, the oven is "pushed" after opening the doors at both ends of the oven. This is accomplished by a pusher machine that rides on a track for the full length of the batteries. The pusher is also equipped with a coal levelling bar. The coke oven door is made of cast iron lined with firebrick and set against a brick or cast iron frame. The joints remaining between the frame and door edge is filled with clay.

Status of bee-hive coke ovens in India

In India, in the early 1970's, there were a large number of bee-hive coke ovens operating in Dhanbad area of Bihar state. The bee-hive ovens require much less capital investment and can be easily started or closed when required. The coke manufactured from these ovens were supplied to foundaries operating in different parts of the country. The production of the bee-hive coke had increased from 0.55 million tonnes in 1970 to 1.52 million tonnes in 1990. Many of these coke ovens are primitive and the gases that are produced in the process are expelled to the atmosphere affecting the local environment adversely. In the early 1990's the Bihar state Pollution Control Board issued notices to all the bee-hive coke oven operators to modify the coke oven design and install a chimney to carry the waste gases. This led to improvements in the design of ovens and also reduced pollution. Many oven operators have adopted the modified version of the improved designs and have benefitted in many ways - reduced pollution and increased output and better quality of the product. In the modified ovens, the sensible and potential heat of the gases was utilized for heating the sole flues to achieve a faster coking rate and reduce the carbonization time. Two improved designs namely, Kumbraj Process (CFRI design) and Dasgupta Process became popular and many ovens in Dhanbad adopted these designs. A brief note on both the improved designs is given in Annexure 1.

Bee-hive Coke Oven at Redi

In India, the production of coke for steel making is normally done in By-product coke-ovens. All the integrated steel plants and many of the new steel plants under construction/planning have adopted the concept of by-product coke ovens for coke manufacture. The bee-hive coke oven plant at Redi is the one of the first such plants in the country installed for supplying coke to the blast furnace. The reason for going in for the bee-hive coke ovens rather than by-product coke oven are - low investment, reduced pollution from the plant, ease of operations and may be improved quality of coke.

At Redi, there are 4 coke-oven batteries (B1, B2, B3, and B4) in operation and each battery has 9 coke ovens. Two batteries are under construction. The design of the ovens has been supplied by M/s Dasgupta and Company, Dhanbad. The size of the oven is 8 m long x 1.83 m wide and 1.2 m high and the capacity of coal charge is about 12 tonnes. Minus 50 mm coal is crushed in a hammer mill and screened. Coal of less than 3

mm size is sent to the coal charging hoppers through a conveyor. The coal is charged into the ovens through 2 hoppers mounted on a trolley operating at the top of the ovens. The coal charge in the ovens is levelled by a levelling bar. After levelling of the coal charge in the oven, the coal bed height is about 1 m. When the coal falls into the hot oven, gasification begins immediately and continues until most of the volatile matter is expelled. Oven gas is burnt in 3 stages namely inside the oven, gas duct and sole flue. Gas is then passed to the waste heat tunnel and then it is sent out via chimney. Controlling dampers are in the main tunnel which connects the waste heat tunnel from both units. Main tunnel is partitioned with vertical dampers for each partitioned chamber so that draught from each unit can be individually controlled. There is another damper near to the chimney base to control chimney draught. Basic controlling is by means of sole damper position at the collecting point of sole flue at each individual oven to the waste heat tunnel.

Coal consumption and coke production

Coke is produced by heating coal to a high temperature resulting in the removal of volatile matter leaving a carbonaceous residue after remaining in the oven for 40-60 hours. The monthwise data on coal charged and coke production for the period from April 1995 to February 1996 is given in Table 3.1. An analysis of the data shows that coke production is taken as 0.7 t per tonne of coal charged. The coal charge is also estimated at an average of 12 t per charge.

Table 3.1. Coal consumption and coke production for the period April 1995-Feb 1996 (Figures in tonnes)

Month	Coal consumed	Coke production
April 1995	3446	2412
May	3356	2349
June	3270	2289
July	2652	1854
August	3116	2181
September	3811	2665
October	4213	2946
November	4057	2837
December	5339	3733
January 1996	5280	3691
February	5160	3607

Note Battery number 4 was commissioned in December, 1995.

Quality of coal charged to the beehive ovens

The coal charged to the coke-ovens at Redi is low ash coking coal imported from China. About 30,000 MT of coal is received at the port in Goa at intervals of about 4 month's and is transported by trucks to the plant at Redi. The analysis of coal is carried out for

each shipment at both destinations. The results of coal analysis for coal shipped in August 1995 and December 1995 is given in Table 3.2.

Table 3.2. Proximate analysis of coal (figure in percentages)

Parameters	August 1995	December 1995[1]	Remarks
Total moisture	8.10	9.20	AR
Inherent moisture	1.13	1.00	AD
Ash	8.62	8.56	AD
Volatile matter	25.79	23.10	AD
Fixed carbon	64.46	67.34	AD
Sulphur	0.43	0.60	AD
Phosphorous	0.020	0.027	AD
Size	0-50 mm	0-50 mm	AD

Note

1/ Li Feng coking coal from China. Cargo analysis report despatched in December 1995 (quantity 33,000). This is the coal which was being used in the ovens in March 1996.

2/ Analysis of coal received in Goa port in August 1995 and analysis done in Goa.

3/ AR: As Received basis, AD: Air dried basis.

A sample of the coal being charged into the ovens was collected in March 96 and analysed in the Shriram Institute for Industrial Research in Delhi. The results of the analysis is given in Table 3.3.

Table 3.3. Ultimate analysis of coal

Ultimate analysis	% by mass (on dry basis)
Ash	8.70
Carbon	73.79
Hydrogen	6.20
Nitrogen	1.12
Sulphur	0.54
Oxygen	9.65 (by difference)

Performance of the coking ovens from 18.1.96 to 3.3.96

The 4th battery of ovens was commissioned in December 1995, and since then all the four batteries have been operating regularly. The performance data of the ovens for the period of 45 days from 18.1.96 to 03.3.96 were collected and analysed. The details of number of charging/pushing, coking time for each charge and the average coking time during the period 18.1.96 - 3.3.96 for each oven is given in Tables 3.4 and 3.5 respectively.

Table 3.4. Number of charges from 18.1.96 to 3.3.96 (45 days)

Oven #	Battery #			
	B1	B2	B3	B4
1	17	16	16	16
2	20	22	19	18
3	20	22	20	18
4	22	21	20	20
5	21	22	18	19
6	21	21	16	19
7	19	20	17	16
8	20	20	18	16
9	15	20	13	12

The average coking time has been calculated by dividing the total time (45 days) by the number of charges and is given in Table 3.5. The net average coking time for batteries B1-B4 has been calculated by the sum of the net time recorded by the plant for each oven, and dividing that by the number of charges and are given in Annexure 2. Figures 3.2, 3.3, 3.4 and 3.5 represent the coke oven performances for each battery.

Table 3.5. Average coking time (hours) from 18.1.96 to 3.3.96 (45 days)

Battery # Oven #	B1	B2	B3	B4
1	63.5	67.5	67.5	67.5
2	54.0	49.1	56.8	60.0
3	54.0	49.1	54.0	60.0
4	49.0	51.4	54.0	54.0
5	51.4	49.1	60.0	56.8
6	51.4	51.4	67.5	56.8
7	56.8	54.0	63.5	67 5
8	54.0	54.0	60.0	67.5
9	72.0	54.0	83.1	90.0

Based on the number of charging per oven for the period from 18.1.96 to 3.3.96, the coal consumed in each battery is estimated at the rate of 12 t per charge. Assuming a coke output of 0.7 t per tonne of coal charged, the coal burnt is the difference between coal charged and coke output i.e. 0.3 t per tonne of coal charge. The coal burning rate has been determined based on this assumption and the details are given in Table 3.6. Figure 3.6 represents overall coke oven performance for all the batteries.

Figure 3.2. Coke oven performance - B1

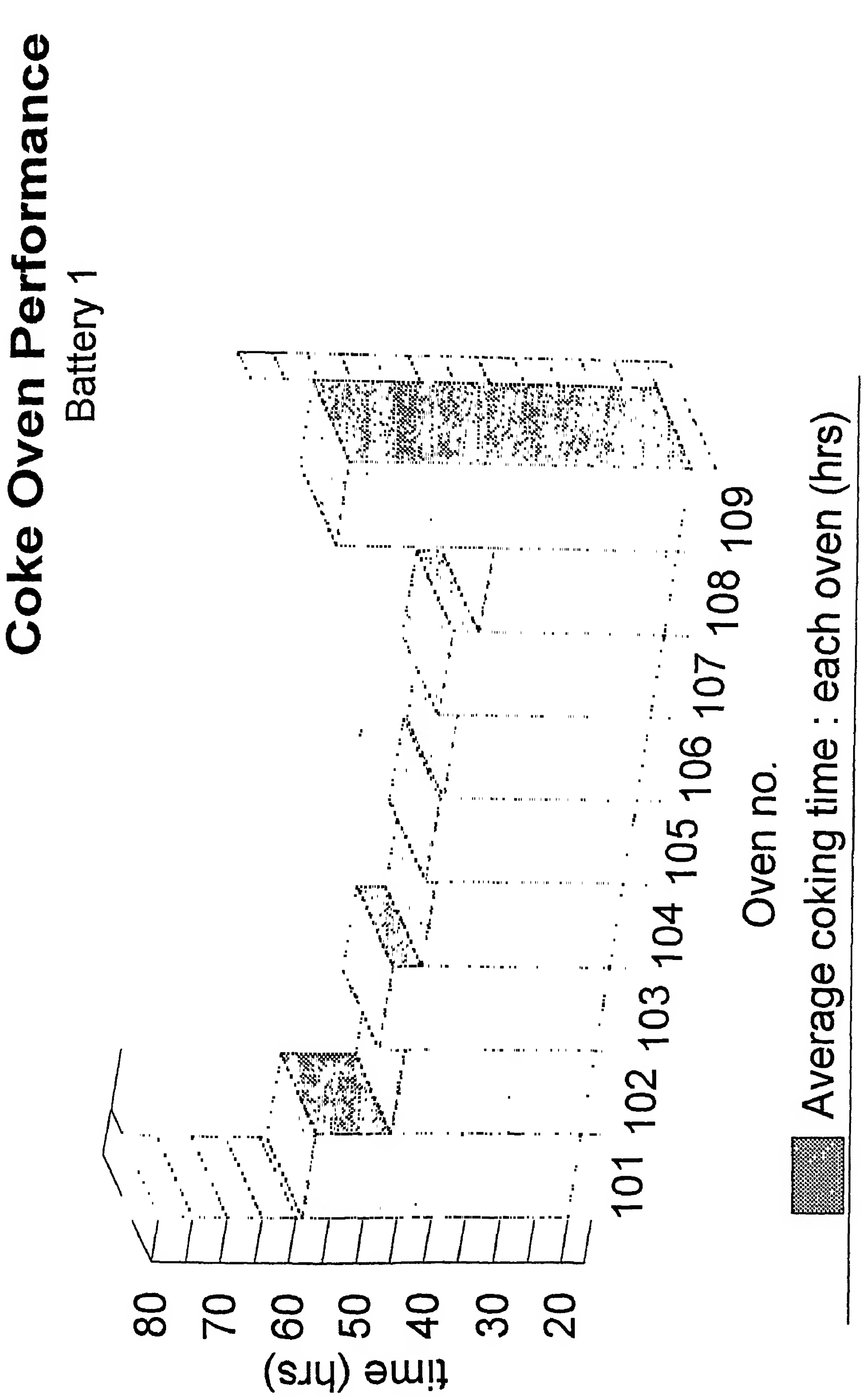


Figure 3.3. Coke oven performance - B2

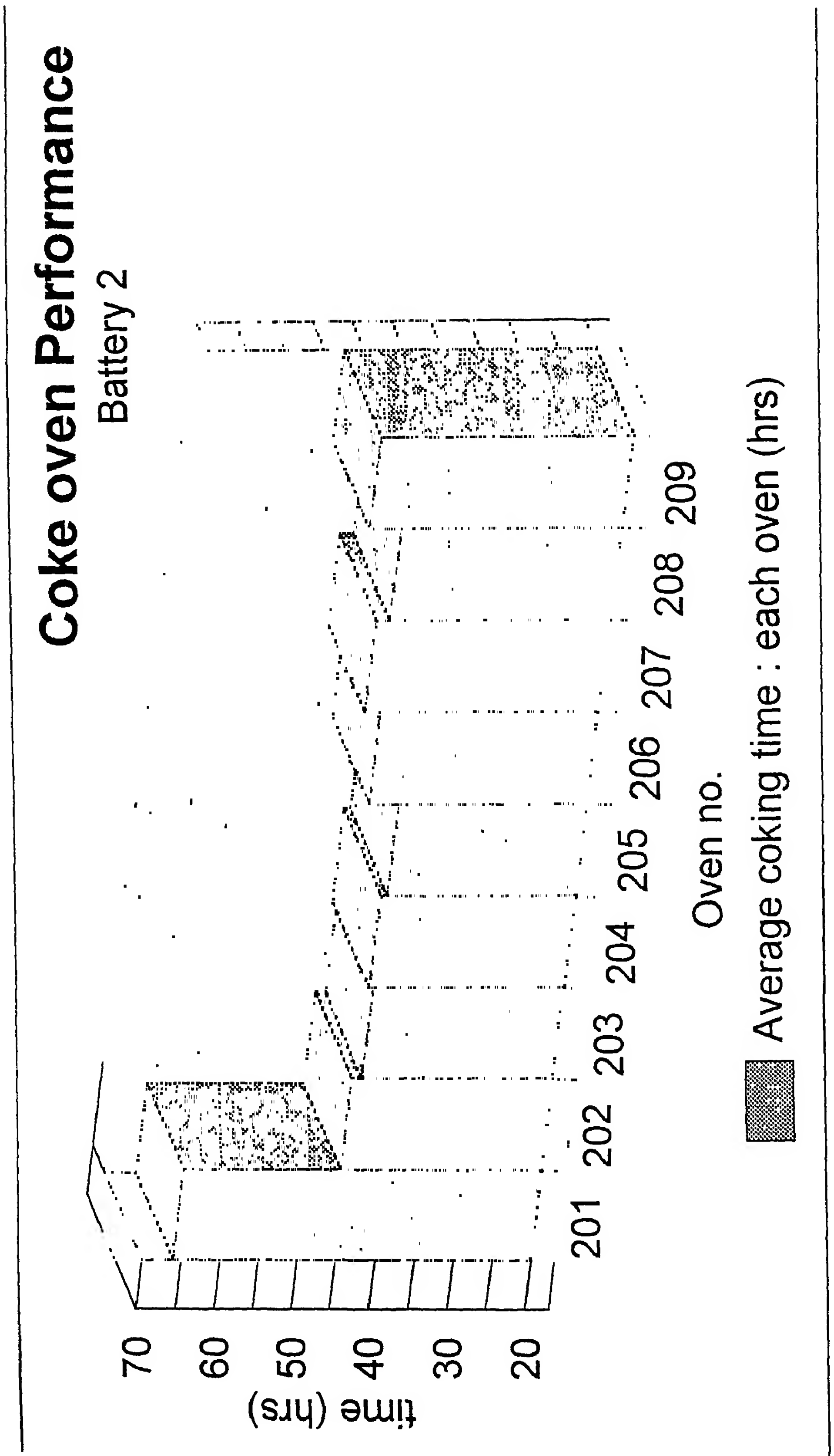


Figure 3.4. Coke oven performance - B3

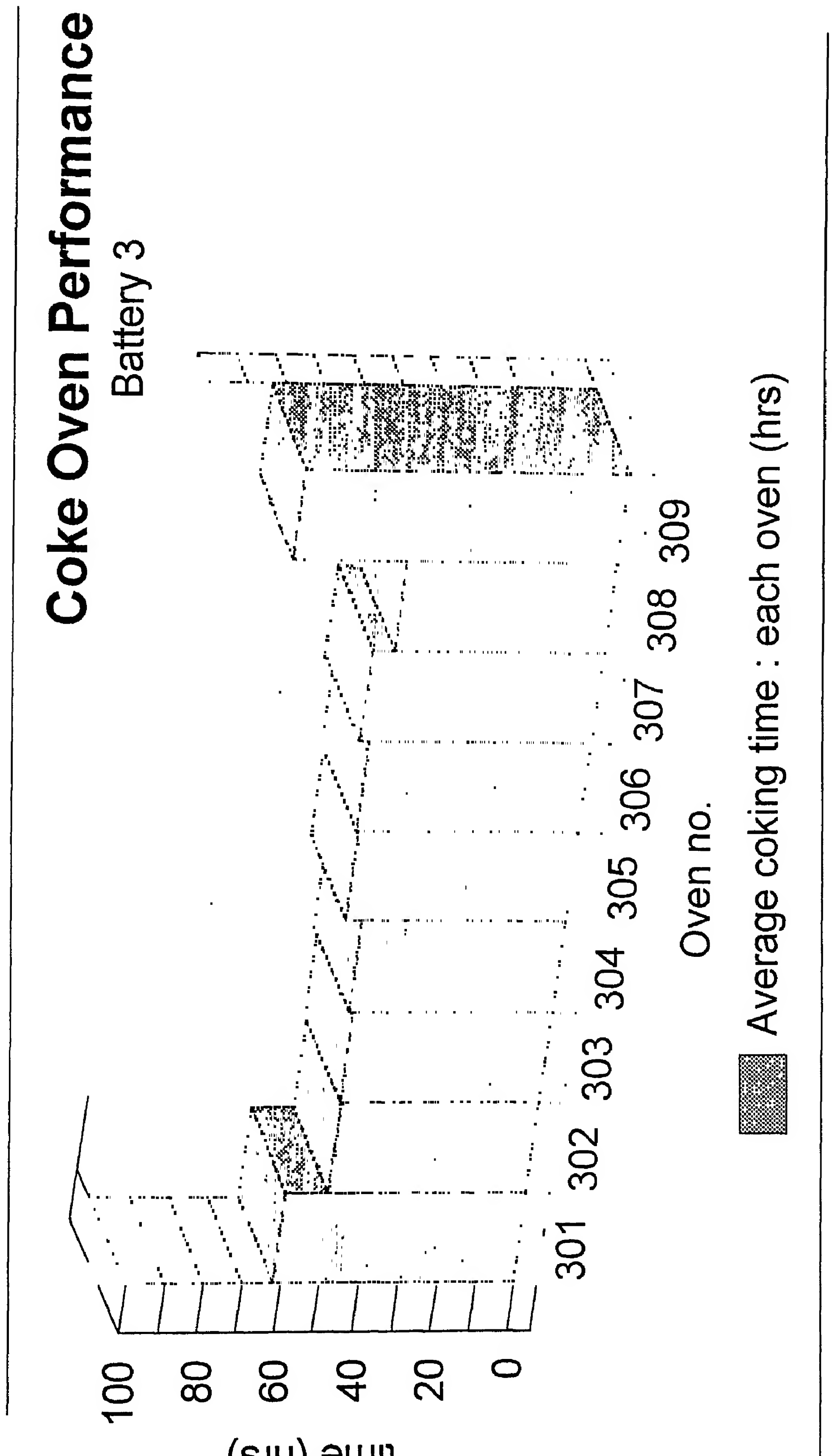


Figure 3.5. Coke oven performance - B4

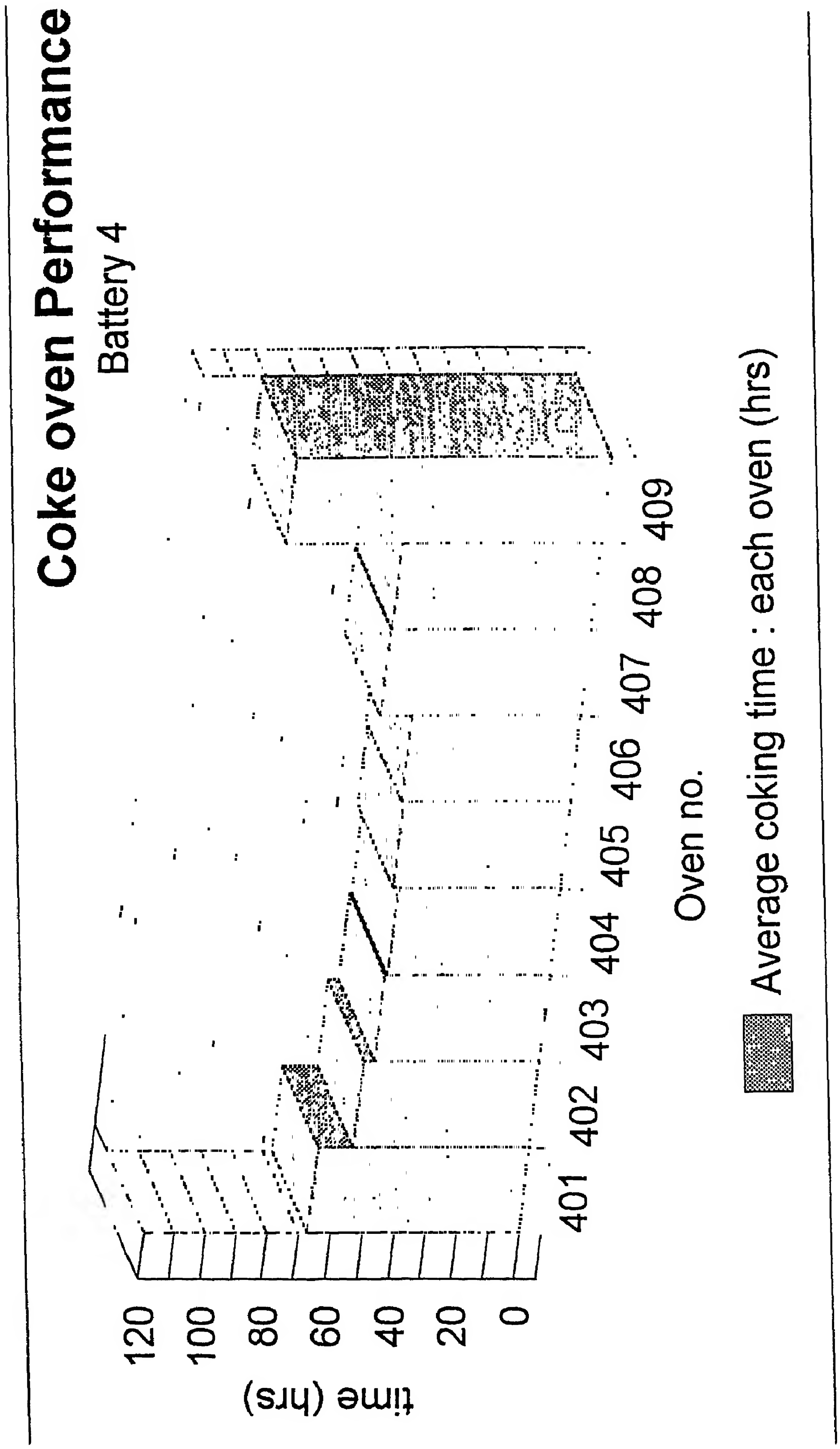


Figure 3.6. Over coke oven performance for all batteries

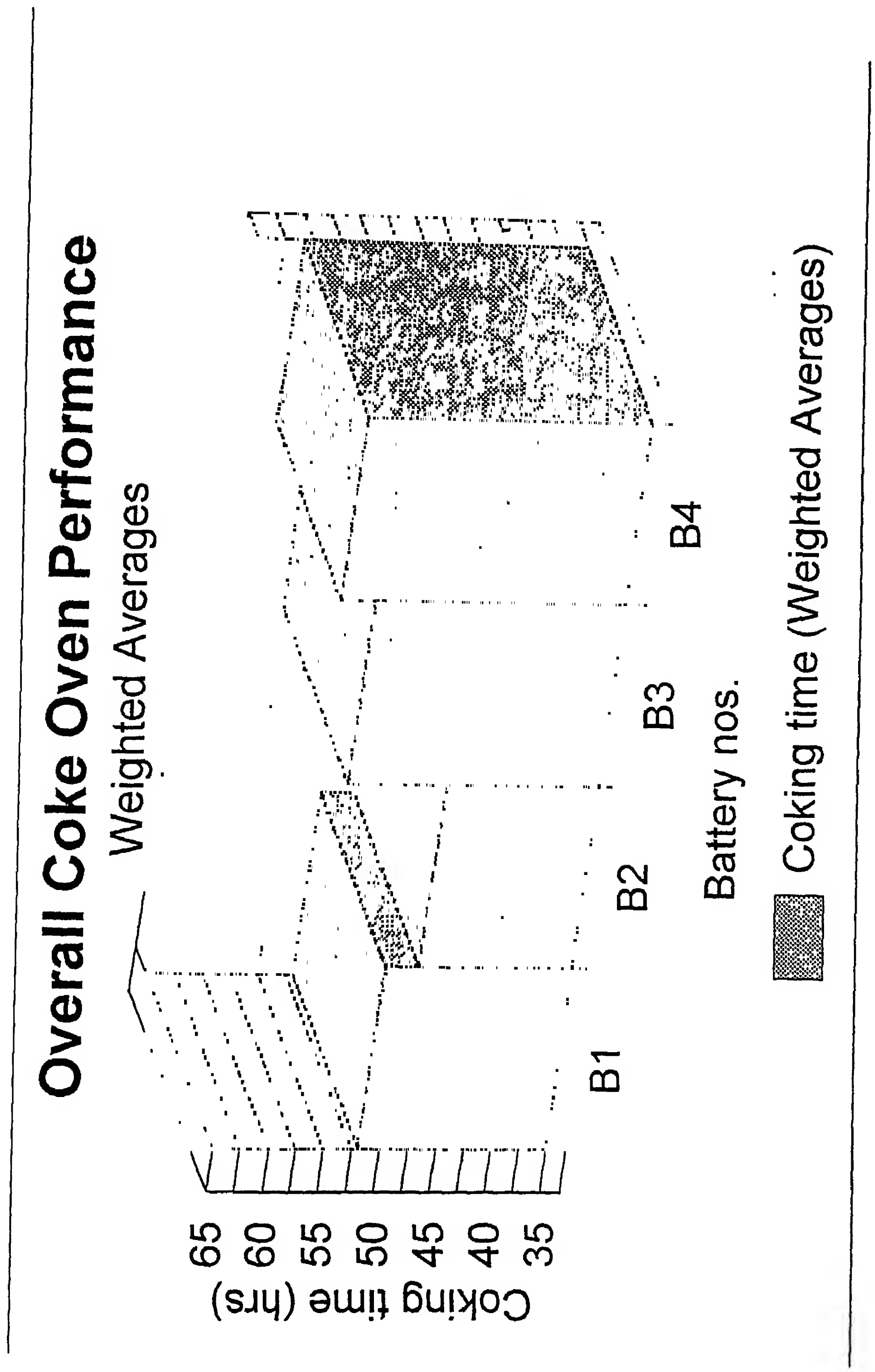


Table 3.6. Coal charged from 18.1.96 to 3.3.96

	Coal charged		Coal burnt
Battery #	t	kg/s	kg/s
B1	2100	0.54	0.162
B2	2208	0.56	0.155
B3	1884	0.48	0.133
B4	1848	0.47	0.130
	8140	2.09	0.628

An analysis of the data reveals the following:

- The average coking time varies considerably for the ovens in a battery and also across batteries. The coking time ranges from 49 hours to 90 hours during the period for which data has been analysed. This corresponds to an 83% difference in performance between the best and the worst.
- The ovens at the end of the batteries take significantly longer time to produce coke and the average coking time varies from 63.5 to 90 hours.
- The coking time for ovens in batteries B1 and B2 are less than for ovens in batteries B3 and B4. The best coking time is 49 hours for oven no.4 in battery B1 and the worst coking time is oven no.9 in battery B4 (90 hours).
- Ovens of batteries B3 and B4 are not performing as well as batteries B1 and B2.
- The coking time is much higher than the designed values for all the ovens (the designed coking time is 36 hours).
- A comparison of the net average coking time and average coking time shows that the average time is greater than the average net coking time. This is perhaps due to the time lost in breakdowns or waiting between charges due to power failure, etc.

Causes for high coking time

Some reasons for high coking time are:

- Excessive air leakages from doors and dampers evidenced by the high O_2 levels in the flue gases.
- High convection and radiation losses from coke oven doors with surface temperatures of (250-260 °C).
- Lack of adequate control of damper opening.
- Manual operation which limits the ability for close control of process.

CHAPTER 4

Financial appraisal

Capital Cost

The project cost has been worked out on the basis of prevailing prices and rates. The ex-works cost of boiler and turbine has been obtained from the manufacturers. To arrive at the total cost of the plant, the cost of auxiliary and other items as listed below have been added to the ex-works cost. The cost of the auxiliary and other items are taken as percentage of the ex-works cost of the boiler/TG system.

The major equipment are,

- 3 waste heat recovery boilers of 5 t/hr capacity generating steam at 44 bar and 445 deg. C.
- 3 MW condensing turbine with generator.
- Gas delivery system.

The ex-works price of boiler vary from Rs 1.5 crores to Rs 4.6 crores. The TG cost is Rs 2 crores, and the gas delivery system is expected to cost Rs 1 crore. A large number of auxiliary plant and equipment shall be required to set up the power station, such as civil works, electricals, control and instrumentation, DM water system. cooling water system, erection and commissioning etc. These costs have been added to the ex-works price of the vendor using a suitable percentage. Taxes have been included in the price. The summary of the cost data is given in Table 4.1.

Table 4.1. Summary of cost data

Equipment	Cost
Boiler and auxiliaries	Rs 3 crore to Rs 9 crore
TG set and auxiliaries	Rs 4 crore
Gas delivery system	Rs 1 crore
Total	Rs 8 crore to Rs 14 crore

The erection and commissioning period of the plant is taken as 6 months and the interest during the construction period is capitalised.

Cost of power generation

The cost of power generation for the proposed power plant has been computed as per conventional method.

Unit cost of generation = Annual expenditure/net units generated

a) Net units generated : For calculation of annual generation a specific generation of 8,000 kWh/KW is considered. Energy consumed by the station auxiliaries has been taken as 5% of the energy generated and the balance is considered as net energy generated.

b) Annual expenditure: This comprises of the following:

- Interest on loan capital taken as 18% per annum.
- Depreciation norms taken as 7.5%.
- Operation and maintenance cost taken as 2.5%.
- Interest on working capital is taken as 24%. The working capital comprises of O&M cost for one month.

c) Cost of power

The unit cost of power, has been calculated for 90% and 100% capacity utilisation of the plant for all the 3 cases. Case 1 relates to the low cost of the boiler. Case 2 relates to the middle cost and Case 3 to the upper cost of the boiler. Table 4.2 gives the summarised data of financial results obtained for all the cases under the two options of capacity utilisation. The details are given in Annexure 3.

$$\text{Cost of power (Rs./kWH)} = \frac{\text{Total cost of production}}{\text{Net generation}}$$

Table 4.2. Summarised data sheet of financial results

Items	Capacity utilisation 90%			Capacity utilisation 100%		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Installed capacity (MW)	3.00	3.00	3.00	3.00	3.00	3.00
Total generation (MkWh)	21.60	21.60	21.60	24.00	24.00	24.00
Auxiliary consumption (MkWh)	1.08	1.08	1.08	1.20	1.20	1.20
Net generation (MkWh)	20.52	20.52	20.52	22.80	22.80	22.80
Total capital cost (Rs. Crores)	8.0	12.0	14.0	8.0	12.0	14.0
O&M cost (Rs. Crores)	0.2	0.3	0.35	0.2	0.3	0.35
Total cost of production (Rs. Crores)	2.26	3.36	3.97	2.26	3.36	3.97
Unit cost of power (Re/kWh)	1.10	1.64	1.93	1.00	1.47	1.74

Payback and internal rate of return

Financial analysis

- Since there was a vast difference in the cost of boilers as supplied by the three firms, 3 cases have been taken for analysis. Case 1 is taken as low cost and Case 2 as medium cost and Case 3 as the upper cost. TG system cost is taken for a 3MW set.
- Two scenarios have been worked out based on the capacity utilisation of the turbine system, i.e., at 90 percent and 100 percent capacity utilisation levels respectively.
- The sale price of power is assumed as Rs 3/kWh for estimating the revenue generated. This rate is the same as the purchased power cost from MSEB. The gross and net revenue generation for 90% and 100% capacity utilisation levels of the plant are given in Table 4.3.

Table 4.3. Gross and Net revenue generation

(Figures in crores)

	90 % capacity utilisation			100 % Capacity utilisation		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Gross Revenue	6.16	6.16	6.16	6.84	6.84	6.84
Net Revenue	3.89	2.79	2.19	4.58	3.48	2.87

Payback period and **internal rate of return** have been calculated for all the cases for 90% and 100% capacity utilisation of the plant.

The payback period is as follows,

Payback period = Total capital cost/Net revenue

Payback (in months)	90 % utilisation (Scenario-1)	100 % utilisation (Scenario-2)
Case 1	25	21
Case 2	51	41
Case 3	77	59

Internal Rate of return

Internal Rate of Return (%)	90 % utilisation (Scenario-1)	100 % utilisation (Scenario-2)
Case 1	53	62
Case 2	25	32
Case 3	17	22

CHAPTER 5

Conclusions and recommendations

Conclusions

Financial Analysis

The capital cost of the plant, the unit cost of power generation, the payback period and internal rate of return have been calculated based on a set of assumptions. Two scenarios have been worked out based on the capacity utilisation of the turbine system, i.e., at 90 percent and 100 percent capacity utilisation levels respectively. For the first scenario, i.e., at 90 percent utilisation and based on the low cost of waste heat boiler, the project will entail a financial outlay of Rs.8 crores and generate net revenues of Rs.3.89 crores per annum, thus giving a payback period of 25 months. The internal rate of return (IRR) is calculated to be 53 percent. For the medium cost of boiler the capital outlay is 12 crores, payback period 51 months and IRR 25 percent. If the upper cost of the waste heat boilers is taken, the capital investment rises to Rs.14 crores with a net revenue generation of Rs.2.19 crores. This gives a pay back period of 77 months and an IRR of 17 percent. In case of the second scenario of 100 percent utilisation of turbine capacity, the Case 1 indicates a financial outlay of Rs.8 crores and net revenue of Rs.4.58 crores with a pay back period of 21 months and IRR of 62 percent. In Case 2 capital cost is 12 crores, net revenue is Rs.3.48 crores with a pay back of 41 months and IRR of 32 percent. In case 3 the capital investment is 14 crores, net revenue is 2.87 crores with a payback of 59 months and IRR of 22 percent. Given the wide variation in cost and internal rate of return, the decision to initiate this project shall be strongly dependent on the final negotiated price of the major equipments.

It may be concluded that the project is attractive for low and medium cost estimates.

Boiler and turbine

- The waste gases available is determined to be 21.3 kg/s for all the six batteries.
- The existing availability of gases would generate 11.5 t/hr of steam at 44 bar and 445 °C. Future improvements in ovens may lead to steam generation of 13.8 t/hr (20 percent improvement of ovens). One boiler of 5 ton capacity may be installed for each pair of batteries B1 & B2, B3 & B4 and B5 & B6 adjacent to the coke ovens..
- Condensing turbine of 3 MW capacity to be installed.

Available heat in the coke oven gases

Direct measurement of the flow velocities could not be done using static pitot tube since the velocities are low. Therefore, flow rates have been determined based on waste gas composition and coal burning rate. Waste gas composition changes from time to time and therefore lower values of air fuel ratio have been selected for computation of the gas flow rate. The burning rate is based on coal charged and coke produced as per available records which are approximate. There could be variations in the coal burning rate.

Performance of the coking ovens

Coking times are much higher than design values. The performance from oven to oven and battery to battery vary greatly, from 49 hours per charge to 90 hours in an extreme case. This is due to:

- Air leakages from doors and dampers are very high. Flue gases show a high oxygen content of 14 percent.
- Convection and radiation heat losses from the coke oven doors and walls are high with surface temperature ranging between 250-260 deg C. This accounts for a heat loss of 1000 kJ/kg coal charged.
  - Lack of adequate control of damper opening.
  - Manual operation which limits the ability for close control of process.

Environment and other benefits of the improved coke ovens

Traditional Beehive coke ovens expell gases to the atmosphere containing volatiles and unburnt particles thereby, producing a lot of contamination and deterioration of the environment. New designs of the bee-hive coke ovens, especially type installed in the pig iron plant at Redi, recycle these gases and burn them inside the ovens. The energy generated by the combustion of volatiles in these gases is partly used for producing coke before being discharged to the atmosphere. Usha India is now considering the scope of generating power by utilising the maximum energy of these hot waste gases. The project would generate power to the tune of 3 MW by maximising on the use of thermal energy in these gases and would minimise the pollution generation like particulate matter and volatiles. In addition to this, income would be generated due to the savings in the amount of power purchased from the grid.

Recommendations

Improving performance of coke ovens

For bringing in immediate improvement in the coke oven performance new door and damper design are nessessary. In addition breakdown in the plant should be reduced to

increase the availability of the plant/ovens. For long term improvements in the coke oven performance systematic study is required. The coking process depends on the following variables.

- Rate of heat transfer.
- Control damper openings (primary, secondary and tertiary).
- Insulation (walls, sides, top, doors), construction materials.
- Geometry of oven, sizes of flow passages, etc.
- Weather (temperature, rain, wind, clouds, etc.).

In order to make a study of the combination of variables which shall give the best results, the following work methodology is suggested:

- Literature survey of existing technologies
- Mathematical modelling of the process
- Design of experiments of the coke oven process
- Parametric study of the various variables

Direct measurement of flow rates of coke oven gases

A cheaper method of estimating the average flow velocities is to inject a tracer gas at the base of the stack, and measure the time for the gas to reach the top of the stack. Alternately, sophisticated instruments for low velocity mesurements have to be procured and used.

Boiler and turbine section

- To enable proper functioning of the coke ovens and the waste heat recovery boiler, a gas collection system would have to be designed and installed.
- An optimisation study for selection of the condenser pressure is suggested to maximise power generation.

R&D needs

The area which needs attention is development of low cost heat recovery boilers for small and medium scale options in process and engineering industries. Basic research in heat and mass transfer, on load cleaning of the fireside deposits besides, the use of unconventional materials for combating the erosion and corrosion of materials have not received enough attention so far. These areas have to be pursued quite seriously by the leading research organisations as well as equipment manufacturing industries. There have been very few demonstrative projects sponsored by the equipment manufacturers or government agencies.

References

- Chemistry of coal utilisation, Vol.I, II and supplementary volume.
  H H Lowry. 1945.
- Alternative coke making technology survey.
  Joel L Sundholm.
- Monograph on coal and coke at Tata Steel.
  Dr A Chatterjee.
- Cost and other data of boilers received from M/s Thermax Limited, Pune; M/s Cogent, Pune; M/s Uttam Industries Engineering Limited, Pune and M/s Caldyn Thermowir Private Limited, New Delhi.
- Cost data of turbine received from M/s Kessels Engineering Works Private Limited, New Delhi.
- Technology evaluation and norms study in boiler - draft report.
- Department of Scientific and Industrial Research. New Delhi. 1988.
- Coke oven plant documents and discussions with officials.

Annexure 1. Beehive cokemaking by KUMBRAJ and Dasgupta designs

Unlike the conventional beehive oven operation, in KUMBRAJ (KU-KUNDA Singh, M - Menon, B - Brahmdeo Singh and Raj - Rajganj) process, which has been recently developed in CFRI, the hot gases leaving the oven chamber pass below the sole (thus providng heat from the bottom of the charge as well), then through a recuperator for preheating the air required for burning of volatiles inside the chamber, and, finally, through a common chimney into the atmosphere. The Kumbraj coke oven is less pollution prone and uses preheated air for commercial production in 1987 at Rajganj, Dhanbad, and the second unit was put into operation in 1989. Each unit consists of 10 ovens in a battery and all the ovens are connected to tall chimney. Each oven in the battery has a coal charging capacity of 91 (approx.), the oven chamber is capable of producing temperatures as high as 1000°C in the coke chamber and each oven is capable of producing about 51 coke per day (i.e. 24h). The details of the ovens are :

Chamber width	5'10" (back)
	6'1" (front)
Chamber length	25'
Height of fall of charge	12'
Coal charge bed height	3'

Comparative coking tests were carried out by carbonising the same blend in Kumbraj ovens and in a "Carbolite" electricity test coke oven installed at CFRI for carbonising under conditions similar to by-product coke ovens. One of the coal blends tested and used was of poor coking quality with 32% ash, 18% VM, 12 mm PLT and CSN of only 1. The results of the tests given in Table 11.11 indicated that:

- Quality of coke produced from the Kumbraj coke ovens was better than that of coke produced from "Carbolite" test oven. In the former case, the crushing fineness of coal was 96.7% below 1mm and 77.3% below 0.5mm while, in the latter case, the 0.5mm fraction was kept at 40% which can be tolerated in by-product coking.
- Higher coling temperature prevailing in the Kumbraj oven (max 1360°C) compared with the Carbolite oven (1100°C) enhanced the fusion and cohesion of the coal particles as well as the cracking of the incipient tar and deposition of carbon on coke, giving it a silvery luster and thus, imparting strength.
- In the Kumbraj coke oven, horizontal plastic layers are formed which are subjected to pressure from the overlying material, causing improvement in coke quality.

Beehive ovens constructed by M/s Dasgupta and Company

The latest beehive ovens constructed by M/s Dasgupta and Compnay for Wellman incandescent India Ltd. (WIIL) are at Rajganj, near Dhanbad. The basic differences between the ovens made by M/s Dasgupta, for WIIL and Kumbraj, are:

- Total preheating system for the air in the case of WIIL ovens including primary air for combustion inside the oven,s secondary air burning flue gases before they are used for side wall heating and tertiary air for burning flue gases before they are used for sole heating. In the case of Kumbraj ovens, primary air is not preheated, only secondary air is preheated.
- Mechanisation up to coal charging system, coal charge levelling and coke pushing in case of ovens constructed by M/s Dasgupta for WIIL.
- Crushing fineness of coal charge in case of WIIL oven is 80% below 3.2 ton against 90.95% below 1mm in case of Kumbraj.
- Provision is made for power generation by utilising heat from the waste flue gases in the WIIL ovens.

WIIL vis-a-vis Kumbraj beehive ovens

Parameters	WIIL	Kumbraj
No of ovens per battery	18	10
Rated capacity per oven,t	12.5	10
Oven size		
Length,m	8	7.6
Width,m	1.8	1.8
Height,m	1.9	1.9
Chimney height,m	36.6	24.4
No of holes on top for charging	3	2+1 for exhaust emission during charging
Coal charging	Mechanical through charging car	Manual by charging hopper
Crushing fineness		
-3.15mm, %	80	-
-1mm, %	-	05.99
Coal bed height,m	0.9	0.9
Coking time,h	36	30 to 38
Charge levelling	Electrically operated leveller	Manually with scrapper plate
Coke pushing	Electrically operated pusher car	Semi-mechanised (using electrically operated winch)
Waste gas utilisation	For heat generation through boiler	not utilized

Annexure 2. Oven performance data from 18.1.96 to 3.3.96 (45 days)

Battery #	Oven #	Total # of charging/ pushing	Time of coking (hrs) for each charge										Average time (hrs)
B1	101	17 readings	62 45	60.0	56.3	56.45	56.0	61.15	62.3	52.3	56.0	60.0	59.1
			61.0	61.0	59.45	58 15	61.0	59.0	62.3				
B1	102	20 readings	50 45	50 3	48 45	48.45	46.0	46.3	45.45	46.3	44.45	50.45	45.7
			49.0	48 0	47.3	48.0	48 0	49.0	45.3	50.0	49.15	52.0	
B1	103	20 readings	62.0	59.3	56.45	53.45	53.3	50.0	47.3	52.0	54.0	51.15	49.2
			53.0	52.0	59.15	47.0	46.0	48.15	47.3	47.3	48.0	51.45	
B1	104	22 readings	53.15	50.45	51.15	47 45	46.0	49.3	46.0	45.15	48.3	48.45	47.5
			46.0	45.0	46.15	44.3	44.3	43.3	44.0	46.0	43.45	52.0	
			55 3	50.3									
B1	105	21 readings	50.15	54.0	53.3	50.15	46.15	40.3	51.0	46.3	48.3	46.3	49.5
			48 3	49.45	52.45	53.3	48.0	43.3	47.0	48.45	51.3	50.0	
			52 3										
B1	106	21 readings	50 3	57.45	53.3	49.3	45.3	42.45	45.0	44.0	45.0	50.3	46.5
			46 3	50.0	53.45	50.3	46.0	48.3	46.3	50.0	49.0	51.45	
			49 45										
B1	107	19 readings	55 0	54 0	52.3	50 3	47.0	51.0	48.45	50.0	51.0	54.0	51.3
			52 3	54 0	53 15	51.3	48 0	51.3	49.3	55.0	48.3		
B1	108	20 readings	49 45	49 0	49.3	48 3	40.0	49.3	49.15	45.45	48.3	45.3	
			46 0	47.15	50.0	47.45	47.3	50.0	48.45	48.0	49.0	47.0	
B1	109	15 readings	79 0	88.0	81.0	76.15	74.15	68.0	67.3	63.3	67.0	80.3	
			67.3	66.15	59.0	58.0	67.0						

Battery #	Oven #	Total # of charging/ pushing	Time of coking (hrs) for each charge										Average time (hrs)
B2	201	16 readings	69.15	79.3	76.0	69.3	67.0	59.3	62.0	68.45	75.3	72.45	
			67.0	61.0	59.3	56.3	58.0	57.0					
B2	202	22 readings	50.15	61.0	46.0	47.0	45.0	45.0	44.0	43.5	42.45	43.0	
			45.0	44.3	46.0	45.0	47.3	47.3	44.0	43.45	43.45	43.0	
			44.45	46.45									
B2	203	22 readings	52.15	51.0	39.15	45.0	43.45	43.3	42.3	47.0	44.15	42.0	
			44.0	44.0	43.0	44.0	44.3	46.0	45.15	43.45	42.3	45.0	
			43.0	45.3									
B2	204	21 readings	44.0	43.45	46.0	42.3	40.0	42.15	47.0	45.3	45.0	45.0	
			45.0	49.3	51.0	45.0	45.15	44.0	46.0	44.0	44.3	-	
			47.0										
B2	205	22 readings	42.3	44.3	41.0	44.15	45.0	42.0	56.0	44.0	46.0	44.0	
			43.15	43.3	44.3	43.3	48.15	43.0	41.0	44.0	41.45	-	
			42.3	45.15									
B2	206	21 readings	46.3	46.0	45.3	46.0	42.3	44.45	46.0	47.0	47.45	46.0	
			50.0	47.45	42.0	57.0	51.45	51.3	52.3	46.45	-	53.3	
			52.0										
B2	207	20 readings	46.3	56.0	51.15	50.0	48.45	48.0	48.0	49.45	53.0	49.0	
			50.0	52.0	54.3	49.45	48.0	46.0	52.15	51.0	52.15	47.0	
B2	208	20 readings	52.15	47.15	49.0	47.0	50.45	49.0	45.0	51.45	49.45	49.3	
			51.0	48.0	46.3	47.0	47.3	46.0	49.0	48.3	46.3	47.45	
B2	209	20 readings	53.3	50.3	56.3	51.45	51.3	48.45	50.45	50.0	50.0	55.0	
			51.3	57.0	52.0	55.0	52.0	54.0	51.0	51.0	53.45	55.15	

Battery #	Oven #	Total # of charging/ pushing	Time of coking (hrs) for each charge										Average time (hrs)
B3	301	16 readings	59.0	57.3	57.15	61.0	67.3	-	57.3	57.15	67.0	65.0	
			69.0	67.0	61.0	59.3	62.3	64.3					
B3	302	19 readings	50.0	52.45	52.0	52.0	48.3	48.3	49.3	45.0	52.45	54.0	
			54.0	49.0	51.3	52.0	56.0	51.3	54.0	48.3	50.45		
B3	303	20 readings	50.45	53.3	55.45	52.0	47.45	55.3	50.3	48.15	48.0	52.0	
			48.15	53.0	52.0	53.3	51.45	53.0	52.0	53.15	50.3	53.15	
B3	304	20 readings	57 0	56.15	54.0	52.3	52.15	52.45	51.3	48.3	53.0	51.3	
			53.3	51.15	54.45	51.15	51.0	50.45	50.15	50.0	52.3	58.0	
B3	305	18 readings	58.0	61.3	62.45	56.0	55.0	54.0	47.3	52.45	63.3	57.45	
			61.15	54.45	62.0	53.3	56.3	55.0	55.3	57.15			
B3	306	16 readings	58.15	58.3	58.0	55.0	53.3	50.3	55.45	52.0	57.0	59.3	
			66.15	60.0	56.3	56.0	61.0	62.0					
B3	307	17 readings	61 45	58.0	-	54.0	54 15	54.0	57.0	58.3	61.3	59.0	
			57 0	65 0	62 0	56.45	69 3	69.3	64.3				
B3	308	18 readings	49.3	57.0	53 45	54.3	56 0	52.0	54.3	51.0	54.45	52.3	
			54 0	52 0	58 3	51.0	51 0	54.0	57.45	65.0			
B3	309	13 readings	78 15	84.3	80 15	86.3	87.0	89.0	83.3	86.3	87.15	77.3	
			78 3	82.3	89.3								

Battery #	Oven #	Total # of charging/ pushing	Time of coking (hrs) for each charge										Average time (hrs)
B4	401	16 readings	77.0	74.0	75.3	64.45	66.15	66.15	60.3	63.3	74.3	66.3	
			65.3	69.3	73.0	60.3	60.3	59.15					
B4	402	18 readings	53.15	57.3	53.0	48 3	52.0	50.3	52.3	52.0	55.0	67.0	
			59.0	63.0	63.0	55.0	61.0	58.3	54.45	56.15			
B4	403	18 readings	56.15	53.3	-	51.45	50.0	55.0	54.0	54.45	51.45	52.0	
			59.45	55.45	49.45	53 0	50 3	51.0	52.3	51.45			
B4	404	20 readings	57.45	51.5	53.3	49.0	51.45	48.45	51.3	*	49.0	56.3	
			51.45	57 45	50.3	51.0	54.0	51 0	51.3	48.45	51.45	58.3	
B4	405	19 readings	55.3	55.3	53.3	57.3	50.0	51.3	53.45	51.0	54.3	54.0	
			53.0	54.0	59.15	61.45	53.45	49.3	51.3	52.3	53.15		
B4	406	19 readings	59.15	54.45	54.3	53.3	48.45	53.0	52.3	53.0	52.0	58.0	
			53.15	51.45	58.3	53 0	51 3	54.0	56.15	57.3	63.15		
B4	407	16 readings	66.49	70.45	64 0	62.0	65 0	62.0	59.3	63.3	62.45	62.0	
			67.15	61 3	61.0	69 3	66.0	73.0					
B4	408	16 readings	59 3	61.3	64 3	64 0	59.0	57.75	65.15	59.45	68.0	67.3	
			66.0	68.0	65.45	65 0	72.0	66.3					
B4	409	12 readings	100.0	106 3	99.0	*	93.45	93.45	92.3	99.0	98.0	108.3	
			115.0	109.3									

Annexure 3. Cost of power, payback and IRR

	Scenario 1			Scenario 2		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Capital cost + Interest	8.03	11.92	14.06	8.03	11.92	14.06
Capital cost without interest	7.39	10.98	12.95	7.39	10.98	12.95
Assume E/L as 1/4						
Equity	1.61	2.38	2.81	1.61	2.38	2.81
Loan	6.42	9.54	11.25	6.42	9.54	11.25
Interest on Loan @18%	1.16	1.72	2.03	1.16	1.72	2.03
Depreciation 7.5%	0.60	0.89	1.05	0.60	0.89	1.05
O & M costs 2.5%	0.20	0.30	0.35	0.20	0.30	0.35
Interest on working capital 24%	0.05	0.07	0.08	0.05	0.07	0.08
Return on equity 16%	0.26	0.38	0.45	0.26	0.38	0.45
Total Operating Cost/yr	2.26	3.36	3.97	2.26	3.36	3.97
Net Revenue per annum	3.89	2.79	2.19	4.58	3.48	2.87
Payback period	2.06	4.27	6.42	1.75	3.43	4.89
Ratio (net capital cost/net revenue)	1.90	3.93	5.91	1.61	3.16	4.51
IRR	52.66	25.46	16.91	61.92	31.69	22.20
Unit cost of production Rs./kWh	1.10	1.64	1.93	0.99	1.47	1.74